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Description

The present invention relates to a film thickness controller for use in an extrusion molding apparatus and a flowing type molding apparatus such as a film sheet manufacturing apparatus.

A thickness controller is known from US-A-3,557,351 comprising a gauge device and a gauge signal processor. The output signal of the gauge signal processor is fed to a controller unit responding to the signal to adjust an actuator being coupled to a controlling device incorporated in a material former. The material former controls a discharge amount of a material. The gauge is provided for detecting variation thickness of the material after the lapse of a certain time.

From EP-A-0 183 401 the use of a reciprocated gauge is already known. According to FR-A-2,330,058 state equations are used, while in the publication Chen et al, IEEE vol.3, 20.06.86, pages 1409-1415, the use of state equation interferences is explained.

A conventional film thickness controller is now described briefly.

An extrusion molding apparatus for manufacturing film or sheet is required to manufacture a molded product such as film or sheet having thickness maintained to a predetermined value. An example of a conventional apparatus having a die provided with an adjusting mechanism which can adjust thickness of film along the width thereof is now described with reference to Figs. 28 to 30. Molten plastic is fed from an extruder 1b (Fig. 28) to a die 2b. The molten plastic is expanded in a manifold 3b in the width direction perpendicular to paper of Fig. 28 showing the die 2b and flows down from a split-shaped outlet 5b of die lips 4b. Then, the molten plastic flowing dwon from the outlet 5b is cooled by a cooling roller 6b and solidified to be film 7b... so that the film is wound on a winder 10b.

A thickness gauge 11b measures thickness of the film 7b. The thickness gauge 11b utilizes radiation due to the natural disintegration of radioactive substance to measure thickness of the film 7b in accordance with degree of reduction of the radiation intensity when the radiation passes through the film 7b. The thickness gauge includes a single detection element which is moved in the reciprocating manner along the width of the film 7b to measure thickness of the film 7b along the width.

It is required that the thickness of the film 7b is maintained to be a predetermined thickness along the width. However, since it is difficult that molten plastic passes through a narrow gap of the die 2b in the same speed along the width, the thickness of the film 7b is not necessarily identical along the width thereof.

Accordingly, thickness adjusting mechanisms 12b which serve to change a discharge amount of molten plastic along the length of the slot of the die lips 4b are disposed dispersedly along the length of the slot of the die lips 4b. As the thickness adjusting mechanism 12b, there are the following types, for example:

(1) Heater type: A multiplicity of heaters are embedded in the die lips 4b along the length of the slot of the die lips 4b and are controlled to change a temperature generated therefrom so that the viscosity of the molten plastic therein is changed and the flowing speed of the molten plastic is changed to control the discharge amount of the molten plastic.

(2) Bolt type: A multiplicity of screws are disposed along the length of the slot of the die lips 4b to change a gap space of the discharge outlet 5b of the slot of the die lips 4b mechanically or thermally or electrically so that the discharge amount of the molten plastic is controlled.

Accordingly, the thickness of the film 7b can be automatically controlled by adjustment of the thickness adjusting mechanism 12b.

For example, as shown in Figs. 2 and 3, a multiplicity of heaters 12a are embedded in a die 2a at both sides of a gap 3a and the heaters 12a are distributed along the width so that the speed of molten plastic flowing through the gap 3a is maintained to constant.

At this time, when a temperature of the heater 12a which is located in a place where thickness of film 6a is thick is reduced, a temperature of molten plastic being in contact with the die 2a is reduced and the viscosity of the molten plastic is increased. Accordingly, the flowing speed of the molten plastic therein is reduced. Thus, the thickness of a portion of the film 6a corresponding to the place where the temperature of the heater 12a is reduced is reduced so that the thicker portion of the film 6a is corrected. Conversely, when the thickness of the film 6a is small, the temperature of the heater 12 which is disposed in a place where the thickness of film is small is increased so that the speed of the molten plastic flowing through the place is increased and the thickness of the film 6a therein is increased to correct the thickness of film.

Fig. 4 is a block diagram of a conventional thickness controller. When a difference between a film thickness measured by a thickness gauge 10 and a set value for the film thickness is applied to a controller 13, the controller 13 supplies a command to a heater 12a to change a temperature of heat generated by the heater 12a. When the temperature of the heater 12a is changed, the flowing speed of the molten plastic in the die 2a is changed so that thickness of a portion of the film corresponding to the place where the temperature of the heater is changed can be controlled.

Fig. 30 is a block diagram of a conventional thickness controller for one operating terminal device of the thickness adjusting mechanism 12b. A controller 13b is supplied with a difference between a thickness b of a portion of the film measured by the thickness gauge 11b and a set value a of thickness. The controller 13b calculates an amount of operation for the adjusting mechanism 12b corresponding to the portion of the film measured by the thickness gauge 11b and supplies it to the adjusting mechanism 12b. When the mechanism 12b is operated, a discharge amount of molten plastic in the die lips 4b is changed and thickness of the portion of the film controlled by the mechanism 12b is changed to effect the thickness control. The thickness control over the whole width of the film can be made by provision of the number of the control loop blocks of Fig. 30 corresponding to the number of places in which the thickness control is performed.

The conventional film thickness controller as described above has drawbacks as follows:

(1) There is a dead time L_1 due to movement of the film from the outlet of the die to the thickness gauge 10 until variation of thickness of the film is detected by the thickness gauge 10 after the variation has been produced at the outlet of the die.

The control system performs a calculation each time a thickness gauge which is reciprocated along the width of the film reaches an end of the film in which the thickness gauge completes reading of thickness data of the film along the width thereof. Consequently, an operation until the thickness gauge reaches the end of the film after the thickness gauge has measured thickness of a portion of the film takes a time, which is a dead time L_2 until the control system starts the calculation actually after the thickness data has been obtained. Accordingly, a dead time after the operation amount for the operating terminal device has been changed and its influence has been detected as a thickness data until the detected thickness data is employed to perform the calculation is a sum of the dead time L_1 described in (1) and the dead time L_2 described above.

As described above, the conventional film thickness controller has a drawback of producing a large dead time. Description is now made to problems due to these drawbacks.

A. Problem due to large dead time:

Fig. 5(a) is a block diagram of a thickness control system in the case where the controller of Fig. 4 involves the deat times L_1 and L_2. Fig. 5(b) is a block diagram of a thickness control system in which the dead times are combined to one equivalent time. A general feedback control system does not contain such a dead time, while the thickness control system contains such a large dead time (L_1 and L_2) as shown in Fig. 5(b).

Consequently, since there is a large phase delay due to the dead time, a gain of a controller can not be increased even if phase compensation is effected in order to attain stability in the control system. Accordingly, the high-speed response and the steady-state accuracy of the control system are deteriorated. Further, the thickness of the film is always influenced by an external disturbance due to variation of an adjacent die lip adjusting mechanism. B. Problem due to interference effect:

In Fig. 30, when an operating terminal device of a portion of the conventional adjusting mechanism 12b is operated, the thickness of a portion of the film corresponding to an adjacent operating terminal device is changed. Accordingly, the operating terminal device of the portion of the adjusting mechanism and the control loop for controlling thickness of a portion of film corresponding to the position of the operating terminal device interfere with each other. Consequently, the following problems occur:

(1) Even if the stability of the control loop shown in Fig. 30 is ensured, since operation of an operating terminal device of the adjusting mechanism 12b is influenced by the control loop which controls thickness of the film corresponding to an adjacent operating terminal device, the control loops interfere with each other and the stability of the whole control system is not ensured when the thickness of the film is controlled over the whole width of the film. Accordingly, in order to eliminate the influence of the mutual interference, the gain of the controller 13b is reduced so that the control system has a low-speed response.

(2) Conversely, when it is considered to design a stable control system constituting a multi-variable system in consideration of the mutual interference between the operating terminal devices of the adjusting mechanism 12b, the control system becomes a very large system since a hundred or more operating terminal devices are usually disposed in the longitudinal direction of the slot of the die lips 4b and there are detected values of the film thickness equal to the number of the operating terminal devices. Accordingly, it is difficult to design such a large system with ensured stability.

3. OBJECT AND SUMMARY OF THE INVENTION

It is an object of the present invention to provide a film thickness controller having a control device which solves the problems due to the dead time in a film thickness controller having a large dead time.

A. SUMMARY OF FIRST INVENTION

A film thickness controller for use in an extrusion molding apparatus and a flowing type molding apparatus of film including a die having a mechanism which controls a discharge amount of molten plastic along the width of the film and a thickness gauge for detecting a variation of thickness of the film after the elapse of a dead time L_1 corresponding to a time required for movement of the film between the die and the thickness gauge, comprises a subtracter for producing a difference between a thickness value detected by the thickness gauge in a predetermined position along the width of the film and a set value of thickness in the predetermined position, an integrator for time-integrating the difference of thickness produced by said subtracter, a memory for storing past time sequence data of operation amounts of an operating terminal device during a time equal to a sum of the dead time L_1 and a time L_2 until the thickness gauge reaches an end of the film after detection of thickness in the predetermined position, an operational calculator for producing the past time sequence data of operation amounts of the operating terminal device stored in said memory and an estimated value of a state variable at a time earlier than a time when the set value of the detected thickness value of film has been inputted by a dead time L, a state shifter for receiving an output of said integrator and an output of said operational calculator and multiplying a coefficient for shifting the state by the dead time L to produce a state estimated value at a predetermined time, a state prediction device for receiving the past time sequence data of operation amounts of the operating terminal device stored in said memory to produce variation of a state based on establishment of input from a certain time to a time after the lapse of the dead time L, an adder for adding an output of said state shifter and an output of said state prediction device to produce the state estimated value at the predetermined time, and an operation amount commander for multiplying a state estimated value at a certain time produced from said adder by a state feedback gain to produce an operation amount command value of said operating terminal device.

According to the first invention, a multiplicity of heaters are disposed along the width of the film to control a temperature of molten plastic which is material of the film, and the thickness gauge detects actual thickness of the film at a position downstream of the flowing film and corresponding to the position of the heater in the width direction of the film. A difference between the detected actual thickness and a set thickness is calculated by the subtractor and is time-integrated by the integrator while a correction command is fed back. Thus, a temperature of the heater is controlled and a temperature of the molten plastic is controlled to adjust the fluidity thereof so that thickness of the film is always maintained within the set value. The phase delay due to the dead time is corrected by estimation of the past state corresponding to the dead time by the operational calculator and time-integration during the time corresponding the past state by the state shifter and the state prediction device.

B. SUMMARY OF SECOND INVENTION

A film thickness controller for use in an extrusion molding apparatus and a flowing type molding apparatus including a die having a slot along which a plurality of operating terminal devices of a discharge amount adjusting mechanism of molten plastic are disposed and a thickness gauge for detecting variation of thickness after the lapse of a dead time corresponding to a time required for movement of the film between the die and the thickness gauge, comprises a thickness data memory for storing thickness data produced by the thickness gauge, a distributor for receiving an output of said thickness data memory and an arrival end identification signal which is produced by the thickness gauge to identify whether the thickness gauge reaches either of both ends of the film, a plurality of basic control means for receiving an output of said distributor and the arrival end identification signal produced by the thickness gauge, a plurality of command value memories each receiving an output of each of said plurality of basic control means, a superposition adder for receiving an output of each of said command value memories, and an operation value memory for receiving an output of said superposition adder and for supplying an output of said operation value memory to said basic control means.

According to the second invention, the following operation is attained.

(1) The thickness gauge measures thickness of the film while moving in the reciprocating manner along the width of the film. Since the film is moved at a certain speed, the thickness gauge measures the film thickness along a locus as shown in Fig. 27. Accordingly, the thickness gauge produces thickness data of a portion of the film corresponding to each operating terminal device sequentially and also produces an arrival end identification signal indicating whether the thickness gauge reaches one end (A) or the other end (B) when the thickness gauge reaches an end of the film.

(2) The thickness data memory stores thickness data of the film which are measured by the thickness gauge over the whole width of the film and which are thickness data of each portion of the film corresponding to each of the operating terminal devices.

(3) The distributor receives the arrival end identification signal of the thickness gauge and further receives the thickness data over the whole width of the film from the thickness data memory at the same time as receiving of the arrival end identification signal. The distributor supplies a set of predetermined number of thickness data from the received thickness data to a predetermined basic control system to be described later.

(4) Each of basic control systems (control means) receives the set of thickness data supplied from the distributor and the arrival end identification signal from the thickness gauge and further receives data set from the operation amount memory described later to calculate operation amount command values for a plurality of adjacent operating terminal devices containing a predetermined operating terminal device so that the thickness of a portion of the film corresponding to the predetermined operating terminal device is controlled to a predetermined value stably.

(5) The command value memories store the operation amount command values of the plurality of operating terminal devices calculated by the corresponding basic control systems, respectively.

(6) The superposition adder receives contents of the command value memories storing the operation amount command values of the basic control systems corresponding to each of operating terminal devices and effects superposition, addition and average operation to the command values of each of the operating terminal devices to define final command values of each of the operating terminal devices.

(7) The operation amount memory stores the operation amount command values of each of the operating terminal devices defined by the superposition adder retroactively to the past by a time corresponding to a sum $L(=L_1+L_2)$ of the dead time L_1 of the thickness gauge and a time L_2 required for movement of the thickness gauge from the position corresponding to each of the operating terminal devices to an end of the film.

As described above, the basic control systems can control thickness of the film corresponding to each of the heaters (operating terminal devices) containing in the own systems to a predetermined value and can control thickness over the whole width of the film by combination of the basic control systems.

4. BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of a controller according to a first embodiment of the first invention;
Fig. 2 schematically illustrates a configuration of a conventional film manufacturing plant;
Fig. 3 is a front view showing an conventional arrangement of heaters embedded in a die;
Fig. 4 is a block diagram of a conventional film thickness controller;
Fig. 5 is a block diagram of a conventional film thickness controller containing dead time, in which Fig. 5(a) is a block diagram having separate blocks expressing dead times L_1 and L_2, respectively, and Fig. 5(b) is a block diagram having a combined block expressing a sum of the dead times L_1 and L_2;
Fig. 6 illustrates a correspondence of positions of five heaters and give thickness detection positions;
Fig. 7 is a block diagram expressing a dynamic mathematical model of film thickness;
Fig. 8 shows a locus of a thickness gauge for detecting thickness of film;
Fig. 9 is a diagram illustrating a time interval of calculation and time-integration section;
Figs. 10, 11 and 12 are diagrams illustrating various time-integration sections;
Figs. 13 and 14 are graphs showing simulation results using an apparatus of the first embodiment of the first invention (when a set value of thickness is changed and when external heat is added to a heater, respectively);
Figs. 15 to 21 are diagrams concerning a second embodiment of the first invention, in which;
Figs. 15, 16 and 17 are diagram illustrating time intervals of calculation and time-integration sections;
Figs. 18 and 19 are graphs showing simulation results illustrating effects in the case where an average dead time L is used as an integration section of a state shifter and a state prediction device; and
Figs. 20 and 21 are graphs showing simulation results (when a set value of thicknes is changed and when external heat is added to a heater, respectively);
Fig. 22 is a block diagram showing a configuration of a controller of a first embodiment of the second invention;
Fig. 23 is a block diagram expressing a dynamic mathematical model of a film thickness manufacturing process of the first embodiment of the second invention;
Fig. 24 is a block diagram showing a configuration of a basic control system of the embodiment;
Fig. 25 illustrates an application procedure of the basic control system of Fig. 24 to thickness control points;
Fig. 26 illustrates a correspondence of positions of five arbitrary operating terminal devices and five thickness detection positions of the embodiment;
Fig. 27 illustrates a locus of a thickness gauge which is reciprocated to detect thickness of film in the em-

bodiment;

Fig. 28 schematically illustrates a configuration of a conventional film manufacturing plant;

Fig. 29 illustrates an arrangement of operating terminal devices embedded in a die of Fig. 28;

Fig. 30 is a block diagram showing a configuration of the conventional film thickness controller;

Figs. 31(a) to 34(a) are graphs showing simulation results of the embodiment when a set value of thickness is changed and Figs. 31(b) to 33(b) are graphs showing simulation results of the embodiment when external heat is added to a heater;

Fig. 35 illustrates a discrete time for determining a gain matrix of an operational calculator of the second embodiment; and

Figs. 36(a) to 39(a) are graphs showing simulation results of the second embodiment when a set value of thickness is changed, and Figs. 36(b) to 39(b) are graphs showing simulation results of the second embodiment when external heat is added to a heater.

5. DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

A1. First Embodiment of First Invention

(a) Transfer Function Matrix G(s)

In order to explain the embodiment, referring to Fig. 6, control of thickness 3' of film to a predetermined value is considered by employing five heaters 1 to 5 and thickness values 1' to 5' of film measured by thickness gauges 10 located corresponding to the heaters 1 to 5. The reason that heaters 1, 2 and 3, 4 adjacent to the heater 3 are considered in order to control the thickness 3' is to set a control system taking interference of the heaters 1, 2 and 4, 5 to the thickness 3' in consideration. Although there are many heaters on both sides of the heaters 1 and 5, it is considered that influence to the thickness 3' by the heaters disposed outside of the heaters 1 and 5 is as small as negligible. Amounts of heat generated by the heaters 1 to 5 are $u_1(t)$, $u_2(t)$, $u_3(t)$, $u_4(t)$ and $u_5(t)$, respectively, and measured values of thickness 1' to 5' are $y_1(t)$, $y_2(t)$, $y_3(t)$, $y_4(t)$ and $y_5(t)$, respectively.

When Laplace transforms of $u_i(t)$ and $y_i(t)$ (i=1-5) are $U_i(s)$ and $Y_i(t)$ (i=1-5), respectively, $U_i(s)$ and $Y_i(s)$ are related to each other by the following transfer function matrix G(s):

$$\begin{pmatrix} Y_1(s) \\ Y_2(s) \\ Y_3(s) \\ Y_4(s) \\ Y_5(s) \end{pmatrix} = \underbrace{\begin{pmatrix} g_1(s) & g_2(s) & g_3(s) & 0 & 0 \\ g_2(s) & g_1(s) & g_2(s) & g_3(s) & 0 \\ g_3(s) & g_2(s) & g_1(s) & g_2(s) & g_3(s) \\ 0 & g_3(s) & g_2(s) & g_1(s) & g_2(s) \\ 0 & 0 & g_3(s) & g_2(s) & g_1(s) \end{pmatrix}}_{\parallel \; G(s)} \begin{pmatrix} U_1(s) \\ U_2(s) \\ U_3(s) \\ U_4(s) \\ U_5(s) \end{pmatrix} \quad (1)$$

$g_1(s)$ is a transfer function which introduces temporal variation of thickness 3' when only an amount of heat generated by the heater 3, for example, is changed. $g_2(s)$ is a transfer function which introduces temporal variation of thickness 3' when only an amount of heat generated by the heater 2 or 4 is changed. $g_3(s)$ is a transfer function which introduces temporal variation of thickness 3' when only an amount of heat generated by the heater 1 or 5 is changed. The equation (1) does not contain a dead time due to movement of the film from an outlet of the die to the thickness gauge. Accordingly, $g_1(s)$, $g_2(s)$ and $g_3(s)$ are expressed by a rational function of Laplacian operator s. Further, non-diagonal items of the transfer function matrix G(s) of the equation (1) express interference to thickness by the adjacent heaters.

(b) State Equation

When the relation between the input $U_i(s)$ and the output $Y_i(s)$ (i-1-5) of the equation (1) is expressed, the following state equation in the canonical form which is convenient for design of the control system is employed:

$$\dot{x}(t) = Ax(t) + Bu(t) \quad (2)$$

$$y(t) = Cx(t) \quad (3)$$

where x is a state vector, u is an input vector in which $u(t)=[u_1(t), u_2(t), u_3(t), u_4(t), u_5(t)]^T$ (where T expresses transposition), and y is an output vector in which $y(t)=[y_1(t),y_2(t),y_3(t),y_4(t),y_5(t)]^T$. The state equations (2) and (3) are controllable and observable.

The state vector means a vector consisting of a set of variables in which a state of the system is defined when the vector is obtained.

The input vector means a set of variables which is a boundary condition of the state equation for the state vector, and the system is controlled by controlling the input vector.

The output vector means a vector consisting of a set of measured amounts defined by the state vector, and the system is controlled by measuring the output vector.

The term "controllable" means that the state vector can be controlled by the input vector.

The term "observable" means that the state vector can be found by the output vector.

(c) Output Equation Taking Dead Time into Consideration

Assuming that a dead time due to movement of the film from an outlet of the die to the thickness gauge is L_1 and a time required for movement of the thickness gauge from the thickness measurement point 3′ to an end of the film is L_2, the whole dead time L of the output vector y is given, as shown in Fig. 5(b), by:

$$L = L_1 + L_2 \quad (4)$$

Accordingly, the output equation (3) is expressed by:

$$y(t) = Cx(t - L) \quad (5)$$

The relation between the input u(t) (amount of heat generated by the heater) and the output y(t) (detected value of the thickness gauge) is shown in Fig. 7 on the basis of the equations (2) and (5).

(d) Arrival End Identification signal

The thickness gauge measures thickness of film while moving in reciprocating manner along the width of the film. Since the film is moved at a certain speed, the thickness gauge measures the film thickness along a locus as shown in Fig. 8. When the position of the thickness 3′ is shown by Ⓐ in Fig. 8, the dead time L_2 due to movement of the thickness gauge is expressed by a time L_2' corresponding to movement between Ⓐ and Ⓑ in Fig. 8.

On the other hand, when the control calculation is made at an end of the film shown by Ⓒ of Fig. 8, the dead time L_2 due to movement of the thickness gauge is expressed by a time L_2'' corresponding to movement between Ⓐ′ and Ⓒ in Fig. 8. As seen from Fig. 8, since the times L_2' and L_2'' are different, the control system which controls the thickness 3′ to a predetermined value is characterized in that the dead time L of Fig. 7 in the case where the control calculation is made at the nd of the film shown by (B) of Fig. 8 is different from that in the case where the control calculation is made at the end of the film shown by (C) of Fig. 8. Accordingly, the thickness gauge produces the arrival end identification signal d indicating an end at which the thickness gauge arrives.

(e) Integrator and Output $\overline{X}_i(t)$ thereof

In order to avoid influence of external disturbance due to thermal conduction from an adjacent heaters to control the thickness 3′ to a set value, an integrator is introduced to integrate deviation $\varepsilon(t)=r_3(t)-y_3(t)$ between the detected value $y_3(t)$ of the thickness 3′ and the set value $r_3(t)$. In the following description, the set value $r_3(t)=0$.

The integrator integrates the deviation $\varepsilon(t)$ until the current time t. However, the deviation can be actually integrated only until the time (t-L) because of the dead time L. Accordingly, an output $\overline{X}_i(t)$ of the integrator is expressed by the following equation:

$$\overline{X}_I(t)=\int_0^t \varepsilon(\tau)d\tau=\int_0^{t-L}\varepsilon(\tau)d\tau+\int_{t-L}^t \varepsilon_L(\tau)d\tau$$

$$=-\int_0^{t-L} y_3(\tau)d\tau-\int_{t-L}^t y_3(\tau)d\tau$$

$$\overline{X}_I(t)=-\int_0^{t-L} C_3X(\tau)d\tau-\int_{t-L}^t C_3X(\tau)d\tau \qquad (6)$$

where C_3 expresses the third line of C matrix of the equation (3).

(f) Augmented System State Vector $\overline{X}(t)$

The first term of the right side of the equation (6) is time-integration of a value capable of being obtained from the thickness gauge until time t and accordingly it can be calculated. However, the integrated value of the second term of the right side can not be obtained and the time integration can not be calculated as it is. Accordingly, in order to obtain prediction of $\overline{X}_I(t)$ at time t, an augmented system as follows in which $\overline{X}_I(t)$ is contained in the state variable is considered.

From the equation (6), the following equation is obtained:

$$\dot{\overline{X}}_I(t)=-C_3X(t-L)-C_3X(t)+C_3X(t-L)=$$

$$-C_3X(t) \qquad (7)$$

From the equations (2) and (7),

$$\begin{bmatrix} X_I(t) \\ X(t) \end{bmatrix} = \begin{bmatrix} 0 & -C_3 \\ 0 & A \end{bmatrix} \begin{bmatrix} X_I(t) \\ X(t) \end{bmatrix} + \begin{bmatrix} 0 \\ B \end{bmatrix} u(t) \qquad (8)$$

By using the state vector $\overline{X}(t)=[\overline{X}_I(t), X(t)]^T$ of the augmented system, the equation (8) is expressed as follows:

$$\dot{\overline{X}}(t)=\overline{A}\overline{X}(t)+\overline{B}u(t) \qquad (9)$$

$$\overline{A}=\begin{bmatrix} 0 & -C_3 \\ 0 & A \end{bmatrix} \qquad \overline{B}=\begin{bmatrix} 0 \\ B \end{bmatrix} \qquad (10)$$

(g) Feedback Gain Matrix

If the state feedback gain matrix for the equation (9) is $\overline{F}=[f_1,F_2]$, the input u(t) is given by

$$u(t) = -\bar{F}\bar{X}(t) = -[f_1, F_2]\begin{bmatrix}\bar{X}_I(t)\\ \\ X(t)\end{bmatrix} =$$

$$-f_1\bar{X}_I(t) - F_2X(t) \qquad (11)$$

where f_1 expresses the first column of F matrix. If the feedback gain matrix F is defined so that all characteristic values of matrix $(\bar{A}-\bar{B}\bar{F})$ are in the stable region if $\bar{X}_I(t)$ and X(t) are obtained, the thickness $y_3(t)$ can be controlled to a predetermined value on the basis of the input u(t) stably. Further, since the matrices $\bar{A}$ and $\bar{B}$ are not influenced by the dead time, this design method can determine the feedback gain matrix $\bar{F}$ as if it is a system having no dead time L and can obtain the high-speed response and the steady-state accuracy of the control system.

(h) Calculation of $\bar{X}_I(t)$ and X(t)

The problem is whether $\bar{X}_I(t)$ and X(t) can be calculated or not. If $\bar{X}_I(t)$ and X(t) at the current time t can not be obtained, the stable control can not be obtained in the case of the above mentioned feedback gain matrix F, and the high-speed response and the steady-state accuracy of the control system are both deteriorated. The problem (2) in the prior art can not be solved.

$\bar{X}_I(t)$ and X(t) are obtained as shown in the equation (12) by initializing the time (t-L) and integrating the equation (9) from the time (t-L) to the time t. Since the input u(t) is already known, the state values $\bar{X}_I(t)$ and X(t) are estimated by performing the integration retroactively to the past by the time L.

$$\begin{bmatrix}X_I(t)\\ \\ X(t)\end{bmatrix} = e^{\bar{A}(t-(t-L))}\begin{bmatrix}X_I(t-L)\\ \\ X(t-L)\end{bmatrix} + \int_{t-L}^{t} e^{\bar{A}(t-\tau)}\bar{B}u(t)dt$$

$$= e^{\bar{A}L}\begin{bmatrix}\bar{X}_I(t-L)\\ \\ X(t-L)\end{bmatrix} + \int_{t-L}^{t} e^{\bar{A}(t-\tau)}\bar{B}u(\tau)d\tau \qquad (12)$$

(i) Calculation of $\bar{X}_I(t-L)$ and X(t-L)

$\bar{X}_I(t-L)$ of the first term of the right side of the equation (12) is expressed on the basis of the equation (7) as follows:

$$\bar{X}_I(t-L) = -\int_0^{t-L}\bar{C}_3X(\tau)d\tau \qquad (13)$$

Since the right side of the equation is calculable and is an integrated value of control deviation of the output $y_3(t)$ at the current time t, the equation (13) is expressed by:

$$\bar{X}_I(t-L) = X_I(t) \quad (14)$$

where $X_I(t)$ is an integrated value of control deviation of the detected value $y_3(t)$ of the thickness 3'.

$X(t-L)$ can be estimated as follows:
From the equations (2) and (5),

$$\dot{X}(t-L) = Ax(t-L) + Bu(t-L) \quad (15)$$

$$y(t) = Cx(t-L) \quad (16)$$

A variable $\omega(t)$ defined by the following equation is introduced.

$$\omega(t) = X(t-L) \quad (17)$$

From the equations (15) to (17), the following equations are obtained.

$$\dot{\omega}(t) = A\omega(t) + Bu(t-L) \quad (18)$$

$$y(t) = C\omega(t) \quad (19)$$

The operational calculator for the equations (18) and (19) is designed to obtain an estimated value $\hat{X}(t-L)=\omega(t)$ from the detected thickness signal $y(t)$.

(j) Dead Time L and Calculation Period

Since the calculation is performed each time the thickness gauge reaches the point Ⓑ or Ⓒ as shown in Fig. 8, that is, at regular intervals of time T.

The relation of the dead time L and the period T of performing the control calculation is described. It is assumed that the position Ⓐ of the thickness 37 exists near the end Ⓒ of the film as shown in Fig. 8. When the control calculation is made at the end Ⓑ of the film, the whole dead time L of the equation (4) is large since the dead time L_2' is large. On the other hand, when the control calculation is made at the end Ⓒ of the film, the whole dead time L is small since the dead time L_2'' is small.

In the embodiment, the dead time L is classified into the following two cases. A case to which the dead time L belongs is determined by the arrival end identification signal produced when the thickness gauge reaches the end of the film.

Case 1: $2T \leqq L < 3T$
Case 2: $T < L < 2T$

(k) Discrete Equation

It is necessary to change the equations (18) and (19) to discrete equations for each time interval T and design the operational calculator.

(1) Case 1 ($2T \leqq L < 3T$)

As shown in Fig. 9, it is assumed that the control calculation is performed at time t_{k-3} to t_{k-1}. It is assumed that at the time t_{k+1}, the output vector $y(k+1)$ is obtained as a set of thickness data and the input vector $u(k)$ is maintained constant during time t_k to t_{k+1}.
From the equation (18), the following equation is derived.

$$\omega(t_{k+1}) = e^{A(t_{k+1}-t_k)}\omega(t_k) + \int_{t_k}^{t_{k+1}} e^{A(t_{k+1}-\tau)} Bu(\tau - L)\,d\tau \qquad (20)$$

If the following variable is introduced, the equation (20) is expressed by the equation (21).

$$\eta = t_{k+1} - \tau$$

$$\omega(t_{k+1}) = e^{AT}\omega(t_k) + \int_0^T e^{A\eta} Bu(t_{k+1} - \eta - L)\,d\eta \qquad (21)$$

The integration of the right side of the equation (21) means that the double-line portion of Fig. 10 is integrated.

Accordingly, the equation (21) is expressed by

$$\omega(t_{k-1}) = e^{AT}\omega(t_k) + \int_0^m e^{A\eta} B d\eta \; u(k-2) + \int_m^T e^{A\eta} B d\eta \; u(k-3) \qquad (22)$$

The following variables ϕ, Γ_1, Γ_2 are introduced.

$$\phi - e^{AT} \qquad (23)$$

$$\Gamma_1 = \int_m^T e^{A\eta} B d\eta \qquad (24)$$

$$\Gamma_2 = \int_0^m e^{A\eta} B d\eta \qquad (25)$$

$$m = 3t - L \qquad (26)$$

If the discrete value $\omega(t_k)$ is expressed by $\omega(k)$, the equation (22) is expressed by

$$\omega(k+1) = \phi\,\omega(k) + \Gamma_1 u(k-3) + \Gamma_2 u(k-2) \qquad (27)$$

The discrete equation of the equation (19) is given by

$$y(k+1) = C\omega(k+1) \qquad (28)$$

By designing the operational calculator for the equations (27) and (28), the estimated value ω (k+1) at time $t=t_{k+1}$ is obtained from the following two equations.

$$\tilde{\omega}(k+1) = \phi\,\hat{\omega}(k) + \Gamma_1 u(k-3) + \Gamma_2 u(k-2) \qquad (29)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K[y(k+1) - C\tilde{\omega}(k+1)] \qquad (30)$$

where K is a feedback gain matrix of the operational calculator.

According to the equations (29) and (30), the state ω (k+19 at time $t=t_{k+1}$ can be estimated from the set of thickness data y(k+1) at time $t=t_{k+1}$. The estimated error $\bar{\omega}(k)=\omega(k)-\hat{\omega}(k)$ at this time is expressed by

$$\bar{\omega}(k+1) = (\phi - KC\phi)\bar{\omega}(k) \qquad (31)$$

Accordingly, if the gain matrix K of the operational calculator is defined so that all the eigen values of matrix $(\phi - KC\phi)$ exist in the stable region, the estimated error can be reduced with the lapse of time.

(2) Case 2 (T<L<2T)

As shown in Fig. 10, it is assumed that control calculation is performed at time t_{k-2}, t_{k-1}, t_k, and t_{k+1}. The integration of the right side of the equation (21) means that the double-line portion of Fig. 10 is integrated. The discrete equation at this time is expressed by

$$\omega(k+i) = \phi\,\omega(k) + \Gamma_1 u(k-2) + \Gamma_2 u(k-1) \qquad (31)$$

m of the equations (24) and (25) is given by

$$m = 2T - L \qquad (32)$$

The estimated value ω (k+1) at time $t=t_{k+1}$ is obtained from the following two equations.

$$\tilde{\omega}(k+1) = \phi\,\hat{\omega}(k) + \Gamma_1 u(k-2) + \Gamma_2 u(k-1) \qquad (33)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K[y(k+1) - C\tilde{\omega}(k+1)] \qquad (34)$$

The equation of the estimated error is the same as the equation (31) and the same thing as the case 1 is applicable in order to reduce the estimated error with the lapse of time.

From the foregoing, the estimated value of the state $(t_{k+1}-L)$ at $t=t_{k+1}$ can be obtained in the following sequence.

(1) If time $t=t_{k+1}$ is a termination time of the calculation execution period T and it is understood from the arrival end identification signal produced from the thickness gauge that the thickness gauge reaches the end (B) of the film as shown in Fig. 8, $\hat{\omega}$ (k+1) is calculated from the equations (29) and (30) and the estimated value $\hat{x}(t_{k+1}-L)=\hat{\omega}$ (k+1) of $x(t_{k+1}-L)$ is obtained.

(2) If time $t=t_{k+1}$ is a termination time of the control calculation execution period T and it is understood from the arrival end identification signal produced from the thickness gauge that the thickness gauge reaches the end (C) of the film as shown in Fig. 8, $\hat{\omega}$ (k+1) is calculated from the equations (33) and (34) and the estimated value $\hat{x}(t_{k+1}-L)=\hat{\omega}$ (k+1) is obtained.

(1) Calculation of Second Term of Equation (12)

The final thing to do is to obtain the integration term of the right side of the equation (12), that is,

$$I=\int_{t-L}^{t} e^{\bar{A}(t-\tau)}\bar{B}u(\tau)\,d\tau \quad \text{is}$$

The integration I is to predict variation of the state

$$\begin{bmatrix} X_I(t) \\ X(t) \end{bmatrix}$$

by the input u(t) from time (t-L) to time t. At this time, the dead time L is classified to the following two cases. A case to which the dead time L belongs is determined by the arrival end identification signal produced from the thickness gauge.

Case 1: $2T \leqq L < 3T$

Case 2: $T < L < 2T$

(1) Case 1. ($2T \leqq L < 3T$)

In the integration I, the double-line portion of Fig. 11 is integrated.

$$\begin{aligned} I(k+1) = & \int_{t_{k+1}-L}^{t_{k+1}-L+T-m} e^{\bar{A}(t_{k+1}-\tau)}\bar{B}d\tau\ u(k-2)+ \\ & \int_{t_{k+1}-L+T-m}^{t_{k+1}-L+T-m+T} e^{\bar{A}(t_{k+1}-\tau)}\bar{B}d\tau\ u(k-1)+ \\ & \int_{t_{k+1}-L+T-m+T}^{t_{k+1}-L+T-m+2T} e^{\bar{A}(t_{k+1}-\tau)}\bar{B}d\tau\ u(k) \qquad (35) \end{aligned}$$

$$m = 3T - L$$

If the following variable is introduced, the integration I is expressed by the equation (37).

$$\eta = t_{k+1} - \tau \quad (36)$$

$$I(k+1) = e^{\bar{A}(2T)}\int_0^{L-2T} e^{\bar{A}\sigma}\bar{B}d\sigma\ u(k-2) + e^{\bar{A}T}\int_0^{T} e^{\bar{A}\sigma}\bar{B}d\sigma\ u(k-1) + \int_0^{T} e^{\bar{A}\sigma}\bar{B}d\sigma\ u(k) \qquad (37)$$

(2) Case 2 (T<L<2T)

In the integration I, the double-line portion of Fig. 12 is integrated.

$$I(k+1) = \int_{t_{k+1}-L}^{t_{k+1}-L+T-m} e^{\bar{A}(t_{k+1}-\tau)}\bar{B}d\tau\ u(k-1) + \int_{t_{k+1}-L+T-m}^{t_{k+1}} e^{\bar{A}(t_{k+1}-\tau)}\bar{B}d\tau\ u(k)$$

If the variable η of the equation (36) is introduced, the integration I is expressed by

$$I(k+1) = e^{\bar{A}T}\int_0^{L-T} e^{\bar{A}\sigma}Bd\sigma\ u(k-1) + \int_0^{T} e^{\bar{A}\sigma}\bar{B}d\sigma\ u(k) \qquad (38)$$

(m) Estimated Value of State Value $[\bar{X}_I(t), X(t)]^T$

From the equations (12), (14), (29), (30), (33), (34), (37) and (38), the estimated value $[\hat{\bar{X}}_I(k+1), \hat{X}(k+1)]^T$ of the state value $[\bar{X}_I(t), X(t)]^T$ at current time $t=t_{k+1}$ is obtained from the following equation.

$$\begin{bmatrix} \hat{\bar{X}}_I(k+1) \\ \\ \hat{X}(k+1) \end{bmatrix} = e^{\bar{A}L}\begin{bmatrix} X_I(k+1) \\ \\ \hat{\omega}(k+1) \end{bmatrix} + I(k+1) \qquad (39)$$

(n) Means for Executing Calculation

Fig. 1 is a block diagram of a controller implementing the first invention. In the first embodiment, each of blocks is operated as follows.

(1) The detected value y(k+1) of film thickness (vector consisting of $y_1(k+1)$, $y_2(k+1)$, $y_3(k+1)$, $y_4(k+1)$ and $y_5(k+1)$) is obtained through a thickness gauge 10 and a sampler 100 at the control calculation execution time $t=t_{k+1}$ of the time interval T. The sampler 100 closes for each calculation execution time $t=t_{k+1}$, that is, the sampler 100 closes each time the thickness gauge 10 reaches the end Ⓑ or Ⓒ of the film shown in Fig. 8. Further, when the thicknes gauge 10 reaches the end Ⓑ or Ⓒ of the film, the gauge 10 produces the arrival end identification signal d which indicates the end to which the gauge has reached.

(2) The detected value $y_3(k+1)$ of the detected film thickness value y(k+1) is supplied to a subtracter 101 which produces thickness deviation $\varepsilon(k+1)=r_3(k+1)-y_3(k+1)$ between the detected value $y_3(k+1)$ and a set value of thickness $r_3(k+1)$.

(3) The integrator 102 is supplied with the thickness deviation $\varepsilon(k+1)$ from the subtractor 101 and produces a time-integrated value of the thickness deviation from the following equation.

$$X_I(k+1) = X_I(k) + 0.5(t_{k+1} - t_k)\{\varepsilon(k) + \varepsilon(k+1)\} \qquad (40)$$

where $\varepsilon(k)$ is a thickness deviation at the last thickness detection time ($t=t_k$) and $X_I(k)$ is an output of the

integrator 102 at $t=t_k$.

The integrator 102 includes a function of an external disturbance compensator and serves to compensate external heat varying the thickness y_3 with heat generated by the heater so that the thickness y_3 is always maintained to be a set value.

(4) When the thickness gauge reaches either end of the film, the thickness gauge produces the arrival end identification signal d. ω (k+1) is calculated from the equations (29) and (30) or (33) and (34) in response to the identification signal d. More particularly, in the equation (29) and (30) for the past time sequence data of heat generated by the heater stored a memory 104, u(k-3) and u(k-2) are supplied to the operational calculator, while in the equations (33) and (34), u(k-2) and u(k-1) together with the detected film thickness value y(k+1) are supplied to the operational calculator, which produces an estimated value $\hat{X}(t_{k+1}\text{-}L)=\hat{\omega}$ (k+1) of the state variable at time $t_{(k+1}\text{-}L)$ earlier than time t_{k+1} by the dead time L determined by the arrival end identification signal d produced by the thickness gauge.

(5) In the calculation of the first term of the right side of the equation (39), the state estimated value $[X_I(k+1), \hat{\omega}(k+1)]^T$ at time $(t_{k+1}\text{-}L)$ is multiplied by a coefficient e^{AL} for shifting the state by the dead time L to obtain the state estimated value $e^{AL}[X_I(k+1), \hat{\omega}(k+1)]^T$ at time t_{k+1}. That is, the output $X_I(k+1)$ of the integrator 102 and the output ω (k+1) of the operational calculator 103 are supplied to state shifter 105, which multiplies them by the coefficient for shifting the state by the dead time L determined by the arrival end identification signal d of the thickness gauge to obtain the state estimated value at time t_{k+1}. Since the magnitude of the dead time L is different depending on the end of the film which the thickness gauge reaches, the coefficient e^{AL} is different depending to the position of the thickness gauge upon control calculation execution, that is, the arrival end identification signal d of the thickness gauge.

The state shift by the input u(k) applied in time domain for only the dead time L is expressed by the second term l(k+1) of the right side of the equation (39) and correction therefor is made by a state prediction device 106.

(6) The second term l(k+1) of the right side of the equation (39) expresses an amount of shift of states for time sequence input data u(k-2), u(k-1) and u(k) applied to the time domain from time $(t_{k+1}\text{-}L)$ to time t_{k+1}. l(k+1) is calculated from the equation (37) or (38) depending on the end of the film which the thickness gauge reaches, that is, depending on the arrival end identification signal produced by the thickness gauge. More particularly, the past time sequence data of the heat generated by the heater (in this case, three data of u(k-2), u(k-1) and u(k)) determined by the magnitude of the dead time L stored in the memory 104 are supplied to the state prediction device 106 and the state variation amount l(k+1) by the input u(k) from time $(t_{k+1}\text{-}L)$ to time t_{k+1}.

(7) Output $e^{AL}[X_I(k+1), \hat{\omega}(k+1)]^T$ of the state shifter 105 and output l(k+1) of the state prediction device are added in adder 107 which produces the state estimated value $[\hat{X}_I(k+1), \hat{X}(k+1)]^T$ at time t_{k+1}. Thus, although the operational calculator 103 can obtain only the state estimated value at time t_{k+1}-L due to the dead time L, the state estimated value at time t_{k+1} can be obtained by integration in the state shifter 105 and the state prediction device 106 for the dead time L. Influence of phase delay due to the dead time L can be eliminated by this operation.

(8) An amount u(k+1) of heat generated by the heater from time t_{k+1} to next time t_{k+2} for control calculation is defined by the following equation using state feedback gain (f_1, F_2).

$$u(k+1) = -f_1\hat{X}_I(k+1) - F_2\hat{X}(k+1) \quad (41)$$

The adder 107 supplies the state estimated value $[\hat{X}(k+1), \hat{X}(k+1)]^T$ at time t_{k+1} to a commander 108 for heat generated by the heater. The commander 108 multiplies the state estimated value $[\hat{X}(k+1), \hat{X}(k+1)]^T$ by the state feedback gain to define a command value of heat generated by the heater.

(9) The above control calculation is executed after the next detected value y(k+2) of film thickness is obtained from the sampler 100 at time $t=t_{k+2}$ of calculation execution when the thickness gauge is moved along the width of the film after the time period T and reaches the opposite film end.

(o) Example of Design

As a first actual example, an example of design is described in the case where transfer functions $g_1(s)$, $g_2(s)$ and $g_3(s)$ are given by the following equations:

$$g_1(s) = \frac{0.044}{S^3 + 2.1S^2 + 2.6S + 0.05} \quad (42)$$

$$g_2(s) = \frac{0.0009}{S^4 + 2.4S^3 + 2.7S^2 + 0.25S + 0.0015} \quad (43)$$

$$g_3(s) = \frac{0.00002}{S^5 + 2.4S^4 + 2.8S^3 + 0.31S^2 + 0.0084S + 0.0004} \quad (44)$$

$u_i(t)(i=1\text{-}5)$ is variation (Kcal/s) of heat generated by the heater, and $y_i(t)(i=1\text{-}5)$ is variation (cm) of thickness of film at the position of the thickness gauge corresponding to the position of the heater. The dead time L_1 due to movement of the film and times L_1' and L_2'' required for movement of the thickness gauge from the thickness control point 3' to the film end assume the following values.

L_1 = 30 seconds

L_2' = 15 seconds

L_2'' = 1.5 seconds

It is assumed that the thickness control point 3' exists at the end Ⓒ of the film as shown in Fig. 8. The control calculation execution period T assumes the following value.

$$T = 16.5 \text{ seconds} \quad (45)$$

In order to design the control system, it is necessary to express the relation between the input u(t) and the output y(t) of the equation (1) and obtain the controllable and observable state equations (2) and (3). G(s) constituted of $g_1(s)$, $g_2(s)$ and $g_3(s)$ of the equations (42) to (44) can be expressed by an equation of the 77th degree, while the controllable and observable equation has been found to be an equation of the 39th degree. Accordingly, the equations (2) and (3) of the 39th degree are obtained from G(s).

(1) Decision of State Feedback Gain Matrix $\bar{F}$

The state feedback gain matrix $\bar{F}$ of the equation (11) is obtained as a solution of an optimum regulator problem for the state equation (8) extended to the equation of the 40th degree on the basis of the equation (2). Since the equation (8) is a state equation of a continuous time system, the equation is changed to a discrete state function with the sampling period T=16.5 seconds and a regulator solution is applied. A proper estimation function is employed to obtain the state feedback gain matrix $\bar{F}$ and as a result the following values are obtained as the eigen values of the matrix ($\bar{A}$-$\bar{B}\bar{F}$).

0.876± 0.02i, 0.79, 0.50± 0.07i, 0.60± 0.09i, 0.60± 0.06i, 0.51

Further, 30 eigen values other than above are not described since the absolute value thereof is less than 0.1 and attenuation is fast. Since all eigen values are within a circle having a radius of 1, stable control can be attained. Since the eigen value having the slowest attenuation is 0.88± 0.02i, the stabilization time Ts can be predicted as about 10 minutes from $(0876)^{35} \fallingdotseq 0.01$ with the definition of control error 1% as follows.

$$Ts = Tx35 = 16.5x35 \text{ sec.} = 577.5 \text{ sec.} = 9.6 \text{ min.}$$

(2) Decision of Feedback Gain K of Operational Calculator

The feedback gain matrix K of the operational calculator of the equation (30) or (34) is obtained for the state equation (27) or (31) of the 39th degree and the output equation (28) of the fifth degree. The gain matrix K is obtained as a solution of the optimum regulator problem so that the matrix $\{\phi^T\text{-}(C\phi)^T K^T\}$ has a stable eigen value. As a result of obtaining the gain matrix K using a proper estimation function, the following values are obtained as eigen values of the matrix (ϕ -K$C\phi$).

0.9077± 0.0002i, 0.9076, 0.9075, 0.9075, 0.772 ± 0.0001i, 0.722, 0.722, 0.722, 0.576± 1×10^{-5}i, 0.576± 1×10^{-5}i, 0.232, 0.232, 0.232, 0.232, 0.232

30 eigen values other than above concentrate to the origin. Since all the values are within a circle having a radius of 1, the estimated error can be reduced with the lapse of time. Since the eigen value having the slowest attenuation is 0.9077, the time To required for attenuation of the estimated error to an initial 1% can be predicted from $(0.9077)^{45} \fallingdotseq 0.01$ as follows.

$$To = Tx45 = 16.5x45 \text{ sec.} = 742.5 \text{ sec.} = 12.4 \text{ min.}$$

(p) Simulation Example (1)

Fig. 13 shows an example of simulation result obtained by calculation using the gain matrices $\bar{F}$ and K obtained above. Fig. 13(a) shows variations (variations of detected values of the thickness gauge) of five thickness values y_1 to y_5 versus time when the set value of thickness y_3 is changed stepwise by 0.02mm. Fig. 13(b) shows variations of amounts u_1 to u_5 of heat generated by the heaters in the same condition as Fig. 13(a).

Since calculation is made after the execution period of 16.5 seconds of calculation after the set value of thickness has been changed, variation of heat generated by the heater occurs after 16.5 seconds from change

of the set value of thickness. An amount of heat generated by the heater is maintained to the same value until 16.5 seconds elapse and the next calculation is made. The calculation is made on the basis of a newly detected value of thickness after 16.5 seconds to change an amount of heat generated by the heater. Accordingly, an amount of heat generated by the heater changes stepwise as shown in Fig. 13(b).

On the other hand, variation of the detected thickness value is detected after the lapse of the dead time L of 31.5 seconds after the amount of heat generated by the heater has been changed after the lapse of 16.5 seconds from the change of the set value. That is, variation of thickness is detected after the lapse of 16.5 + 31.5 = 48 seconds after the set value of thickness has been changed. Thickness y_3 is exactly changed to a set value and the change is substantially symmetrical to the thickness y_3. Variation of heat generated by the heater u_3 is largest, variations by the heaters u_2 and u_4 are largest next to the heater u_3, and variations of the heaters u_1 and u_5 are smallest.

The stabilization time is about 18.5 minutes which is considerably large as compared with the stabilization time of 12.4 minutes calculated by the eigen value of the operational calculator (the stabilization time by the eigen value of the regulator is still shorter). This is based on the following reason.

In order to prevent the command value of heat generated by the heater from being changed largely for each calculation, the command value is defined with weight added as follows.

$$u_{d,k} = Wu_{d,k-1} + (1-W)u_k \quad (46)$$

where

$u_{d,k}$: command value of heat defined by the calculation time $t=t_k$,
$u_{d,k-1}$: command value of heat defined by the last calculation time $t=t_{k-1}$,
u_k: command value of heat calculated at the calculation time $t=t_k$, and
W: weight coefficient.

In this simulation, W=0.8. This means that when the calculation period T=16.5 seconds is considered, a time delay corresponding to a delay of first order having a time constant of 74.65 seconds is added to the heat commander. Accordingly, it is considered that the stabilization time of thickness control of Fig. 13 is larger than the stabilization time estimated by the eigen value of the operational calculator. Then, even if the thickness control is in the stabilization state, the command value of heat changes for each calculation. The reason is because the magnitude of the dead time L of the first term e^{AL} of the right side of the equation (39) which is one of the calculation equations is different in one end Ⓑ and the other end Ⓒ of the film as shown in Fig. 8.

When the present control system is applied actually, the same calculation equation as that applied to the thickness y_3 is applied to each of thicknesses y_1, y_2, y_4, and y_5 and each command value of heat may be produced as a sum of results of the calculation equations. It will be understood that the control system considerably reduces influence of the dead time since the time required for stabilizing variation of thickness when heat generated by the heater is changed stepwise without control of heat is about 10 minutes.

(q) Simulation Example (2)

The second actual example is now described with reference to Fig. 14, which shows a control result when external heat of 8.4 wattage is applied to the heater u_3. Fig. 14(a) shows variations of thickness values y_1 to y_5 versus time, and Fig. 14(b) shows variations of heat u_1 to u_5 generated by the heaters versus time. As shown in Fig. 14(a), although the thickness y_3 is once increased by the external heat of the heater u_3, the thickness y_3 is returned to the original set value by changing the amounts of heat generated by the heaters u_1 to u_5 and the stabilization time is about 18.5 minutes in the same manner as Fig. 13. It is understood that variation due to the external disturbance is exactly compensated by introducing the integrator in the present control system.

The thickness values y_2 and y_4 are once increased by influence of external heat through thermal conduction along the width of the die. The thickness values y_1 and y_5 are also influenced similarly, although the influence is small as compared with y_2 and y_4. In order to cancel the influence of such external heat, reduction of heat generated by the heater u_3 is largest, reduction by the heaters u_2 and u_4 is largest next to the heater u_3, and reduction by the heaters u_1 and u_5 is smallest. When external heat is applied to the heater u_3, other thickness values y_1, y_2, y_4 and y_5 are also changed, although such interference effect can be canceled by applying the same calculation equation as that for the thickness value y_3 to each of the thickness values y_1, y_2, y_4 and y_5.

A2. Second Embodiment of First Invention

(a) Relation to First Embodiment of First Invention

In the second embodiment, the process that the same elements as in the first embodiment are utilized, the equations (1) to (19) are derived, the operational calculator for the equations (18) and (19) is designed and

the estimated value $\hat{X}(t-L)=\hat{\omega}((t)$ of $X(t-L)$ is obtained from the detected value of thickness $y(t)$ is quite identical with that of the first embodiment.

In the second embodiment, a known $\hat{\omega}(t_k)$ obtained by the calculation performed in the step just before the current step is used to obtain $\hat{\omega}(t_{k+1})$.

(b) Dead Time

In the second embodiment, the calculation is also executed each time the thickness gauge reaches the end Ⓑ or Ⓒ of the film as shown in Fig. 8. That is, the calculation is executed at regular intervals of time T. The time T is a time required for movement of the thickness gauge along the width of the film.

On the other hand, the dead time L for the position Ⓐ of thickness 3 is different depending on the end Ⓑ and the end Ⓒ. That is,
Dead time by calculation for the end Ⓑ : $L_B=L_1+L_2''$ (47)
Dead time by calculation for the end Ⓒ : $L_C=L_1+L_2''$
It is apparent that $L_B>L_C$ for the position Ⓐ. In the description below, it is assumed that L_B and L_C satisfy $T<L<2T$.

(c) Known $\hat{\omega}(t_k)$

Fig. 15 is a diagram for explaining the calculation for the end Ⓑ for obtaining the estimated value $\hat{\omega}(t_{k+1}-L_B)$. It is assumed that the calculation is made at time t_{k-2} to t_{k+1}. Further, it is assumed that the input u(k) of the heater is maintained to constant from t_k to t_{k+1}.

It is assumed that the thickness gauge reaches the end Ⓑ at time t_{k+1}. Accordingly, it is considered that the thickness gauge has reached the end Ⓒ at the past time t_k before time t_{k+1} by time T. Thus, it is assumed that the estimated value $\hat{\omega}(t_k)=\hat{X}(t_k-L_C)$ has been obtained in the calculation for the end Ⓒ executed at time t_k. In the calculation for the end Ⓑ executed at time t_{k+1}, the known $\hat{\omega}(t_k)$ is employed to obtain the estimated value $\hat{\omega}(t_{k+1})=\hat{X}(t_{k+1}-L_B)$.

Fig. 16 is a diagram for explaining the calculation for the end Ⓒ for obtaining the estimated value $\hat{X}(t_{k+1}-L_C)$. It is assumed that the thickness gauge reaches the end Ⓒ at time t_{k+1} and the thickness gauge has reached the end Ⓑ at the past time t_k earlier than time t_{k+1} by time T. In the calculation for the end Ⓒ executed at time t_{k+1}, the known $\omega(t_k)$ is employed to obtain the estimated value $\hat{\omega}(t_{k+1})=\hat{X}(t_{k+1}-L_C)$.

As seen from Figs. 15 and 16, the time interval T of the calculation is constant, while since the dead times L_B and L_C for the ends Ⓑ and Ⓒ, respectively, are different, the time difference expressing the estimated values $\hat{\omega}(t_k)$ and $\hat{\omega}(t_{k+1})$ is different from the time interval T. Accordingly, the estimated value $\omega(t_{k+1})$ is obtained from the equations (18) and (19) as follows.

(d) Discrete Equation (18) for the End Ⓑ

The calculation for the end Ⓑ shown in Fig. 15 is first considered. The known estimated value $\hat{\omega}(t_k)=\hat{X}(t_k-L_C)$ is expressed by $\hat{X}(to)$. The estimated value $\hat{\omega}(t_{k+1})=\hat{X}(t_{k+1}-L_B)$ to be obtained is expressed by $\hat{X}(t_1)$. The estimated value $X(t_1)$ of state variable at time t_1 is estimated from the equation (18) on the basis of the known $X(to)$ and inputs after time to.

$$\tilde{X}(t_1) = e^{A(t_1-to)}\hat{X}(to)+\int_{to}^{t_1} e^{A(t_1-\tau)}Bu(\tau)d\tau \quad (48)$$

$$to = t_k - L_C,\ t_1 = t_{k+1} - L_B,\ t_1 - t_0 = T - L_B + L_C$$

When a new variable $\eta = t_1-\tau$ is introduced, the estimated value $\tilde{X}(t_1)$ is transformed as follows:

$$\tilde{X}(t_1) = e^{A(t_1-to)}\hat{X}(to)+\int_0^{t_1-to} e^{A\eta}Bu(t_1-\eta)d\tau \quad (49)$$

Since the integration of the right side of the equation (49) means that the double-line portion of Fig. 15 is in-

tegrated, the equation (49) is expressed by the following equation.

$$\tilde{X}(t_1) = e^{\Lambda(T-L_B+L_C)}\hat{X}(t_0) + \int_0^{m_B} e^{\Lambda\eta} B d\eta \; u(k-1) + \int_{m_B}^{T-L_B+L_C} e^{\Lambda\eta} B d\eta \; u(k-2) \qquad (50)$$

$$m_B = 2T - L_B$$

where u(k-1) is a heater input from time t_{k-1} to t_k, and u(k-2) is a heater input from time t_{k-2} to t_{k-1}. If $\tilde{X}(t_1)= \tilde{\omega}(t_{k+1})$ and $\hat{X}(t_0)=\hat{\omega}(t_k)$, the equation(50) is expressed by

$$\tilde{\omega}(k+1) = e^{\Lambda(T-L_B-L_C)}\hat{\omega}(k) + \int_0^{m_B} e^{\Lambda\eta} B d\eta \; u(k-1) + \int_{m_B}^{T-L_B+L_C} e^{\Lambda\eta} B d\eta \; u(k-2) \qquad (51)$$

where the discrete value $\omega(t_k)$ is expressed by $\omega(k)$.

(e) Discrete Equations (18) for the End Ⓒ

The calculation for the end Ⓒ shown in Fig. 16 is considered. At this time, in the equation (49)

$$t_0 = t_k - L_B,\; t_1 = t_{k+1} - L_C,\; t_1 - t_0 = T - L_C + L_B$$

By integrating the double-line portion of Fig. 16, the following equation is obtained.

$$\tilde{X}(t_1) = e^{\Lambda(T-L_C+L_B)}\hat{X}(t_0) + \int_0^{m_B} e^{\Lambda\eta} B d\eta \; u(k-1) + \int_{m_C}^{T-L_C+L_B} e^{\Lambda\eta} B d\eta \; u(k-2) \qquad (52)$$

$$m_C = 2T - L_C$$

If $\tilde{X}(t_1)= \tilde{\omega}(t_{k+1})$ and $\hat{X}(t_0)=\hat{\omega}(t_k)$, the estimated value $\hat{\omega}(t_{k+1})$ is given from the equation (52) by

$$\tilde{\omega}(k+1) = e^{\Lambda(T-L_B-L_C)}\hat{\omega}(k) + \int_0^{m_C} e^{\Lambda\eta} B d\eta \; u(k-1) + \int_{m_C}^{T-L_B+L_C} e^{\Lambda\eta} B d\eta \; u(k-2) \qquad (53)$$

(f) Discrete Equation for Equation (19)

The discrete equation for the equation (19) is given by

$$y(k+1) = C\omega(k+1) \qquad (54)$$

(g) Calculation of Estimated value $\hat{\omega}$ (k+1)

By designing the operational calculator in accordance with the equations (51), (53) and (54), the estimated value $\hat{\omega}$ (t_{k+1}) at $t=t_{k+1}$ is obtained as follows.

The calculation equation of the estimated value ω (k+1) for the end Ⓑ is given by

$$\tilde{\omega}(k+1) = \phi_B \hat{\omega}(k) + \int_0^{m_B} e^{A\eta} B d\eta\, u(k-1) + \int_{m_B}^{T-L_B+L_C} e^{A\eta} B d\eta\, u(k-2) \quad (55)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K_B[y(k+1) - C\tilde{\omega}(k+1)] \quad (56)$$

where $\phi_B = e^{A(T-L_B+L_C)}$

K_B=gain matrix of the operational calculator.

The calculation equation of the estimated value $\hat{\omega}$ (k+1) for the end Ⓒ is given by

$$\tilde{\omega}(k+1) = \phi_C \hat{\omega}(k) + \int_0^{m_C} e^{A\eta} B d\eta\, u(k-1) + \int_{m_C}^{T-L_C+L_B} e^{A\eta} B d\eta\, u(k-2) \quad (57)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K_C[y(k+1) - C\tilde{\omega}(k+1)] \quad (58)$$

where $\phi_C = e^{A(T-L_C+L_B)}$

K_C=gain matrix of the operational calculator.

According to the equations (55) and (58), the state variable ω (k+1) at $t=t_{k+1}$ can be estimated by a set of thickness data y(k+1) at $t=t_{k+1}$.

(h) Estimated Error $\bar{\omega}$ (k)

At this time, the estimated error $\bar{\omega}(k)=\omega(k)-\hat{\omega}(k)$ is expressed by the following equation:

The estimated error $\bar{\omega}$ (k+1) for the end Ⓑ is given by

$$\bar{\omega}(k+1) = [\phi_B - K_B C \phi_B]\bar{\omega}(k) \quad (59)$$

The estimated error $\bar{\omega}$ (k+1) for the end Ⓒ is given by

$$\bar{\omega}(k+1) = [\phi_C - K_C C \phi_C]\bar{\omega}(k) \quad (60)$$

Accordingly, if the gain matrices K_B and K_C of the operational calculator are defined so that all eigen values of the matrices $[\phi_B - K_B C\phi_B]$ and $[\phi_C - K_C C\phi_C]$ are in the stable domain, the estimated value can be reduced with the lapse of time.

(i) Summary of Calculation of Estimated Value of $\hat{\omega}$ (k+1)

From the foregoing, the estimated value of the state $X(t_{k+1}-L)$ at $t=t_{k+1}$ can be obtained in accordance with the following sequence.

(1) When $t=t_{k+1}$ is a termination time of the period T of calculation execution and it is discriminated on the basis of the arrival end identification signal produced by the thickness gauge that the thickness gauge has reached th end Ⓑ of the film shown in Fig. 8, $\hat{\omega}$ (k+1) is calculated from the equations (55) and (56) and the estimated value $\hat{X}(t_{k+1}-L_B)=\hat{\omega}(k+1)$ of $X(T_{k+1}-L_B)$ is obtained.

(2) When $t=t_{k+1}$ is a termination time of the period T of calculation execution and it is discriminated on the basis of the arrival end identification signal produced by the thickness gauge that the thickness gauge has reached th end Ⓒ of the film shown in Fig. 8, $\hat{\omega}$ (k+1) is calculated from the equations (57) and (58)

and the estimated value $\hat{X}(t_{k+1}-L_C)=\hat{\omega}(k+1)$ is obtained. Thus, the first term of the right side of the equation (12) can be calculated.

(j) Integration of Second Term of Equation (12)

The final thing to do is to obtain the integration term of the right side of the equation (12), that is,

$$I = \int_{t-L}^{t} e^{\bar{A}(t-\tau)}\bar{B}u(\tau)d\tau$$

This integration term I is to predict variation of the state

$$\begin{bmatrix} X_I(t) \\ X(t) \end{bmatrix}$$

by the input u(t) from time (t-L) to time t. The integration I is to integrate the double-line portion of Fig. 17.

$$I(k+1) = \int_{t_{k+1}-L}^{t_{k+1}-L+T-m} e^{\bar{A}(t_{k+1}-\tau)}\bar{B}d\tau\ u(k-1) + \int_{t_{k+1}-L+T-m}^{t_{k+1}} e^{\bar{A}(t_{k+1}-\tau)}\bar{B}d\tau\ u(k)$$

$$m = 2T - L$$

If a new variable $\eta = t_{k+1}-\tau$ is introduced, the integration I(k+1) is expressed by

$$I(k+1) = e^{\bar{A}T}\int_{0}^{L-T} e^{\bar{A}\sigma}\bar{B}d\sigma\ u(k-1) + \int_{0}^{T} e^{\bar{A}\sigma}\bar{B}d\sigma\ u(k) \quad (61)$$

Since the dead time L is different depending on the calculation for the ends Ⓑ and Ⓒ, the equation (61) is described as follows.

The integration $I_B(k+1)$ for the end Ⓑ is given by

$$I_B(k+1) = e^{\bar{A}T}\int_{0}^{L_B-T} e^{\bar{A}\sigma}\bar{B}d\sigma\ u(k-1) + \int_{0}^{T} e^{\bar{A}\sigma}\bar{B}d\sigma\ u(k) \quad (62)$$

The integration $I_C(k+1)$ for the end Ⓒ is given by

$$I_C(k+1) = e^{\bar{A}T}\int_{0}^{L_C-T} e^{\bar{A}\sigma}\bar{B}d\sigma\ u(k-1) + \int_{0}^{T} e^{\bar{A}\sigma}\bar{B}d\sigma\ u(k) \quad (62)$$

(k) Estimated value $[\hat{\bar{X}}_I(k+1), \hat{X}(k+1)]^T$

From the equations (12), (14), (55), (56), (57), (58), (62) and (63), the estimated value $[\hat{\bar{X}}_I(k+1), \hat{X}(k+1)]^T$ of the state value $[\bar{X}_I(t), X(t)]^T$ at the current time $t=t_{k+1}$ is obtained by the following equations.

The estimated value for the end Ⓑ is given by

$$\begin{bmatrix} \hat{\bar{X}}_I(k+1) \\ \\ \hat{X}(k+1) \end{bmatrix} = e^{\hat{A}L_B} \begin{bmatrix} X_I(k+1) \\ \\ \omega(k+1) \end{bmatrix} + I_B(k+1) \qquad (64)$$

The estimated value for the end Ⓒ is given by

$$\begin{bmatrix} \hat{\bar{X}}_I(k+1) \\ \\ \hat{X}(k+1) \end{bmatrix} = e^{\hat{A}L_C} \begin{bmatrix} X_I(k+1) \\ \\ \hat{\omega}(k+1) \end{bmatrix} + I_C(k+1) \qquad (64)$$

(1) Discontinuity of Estimated Value $[\hat{\bar{X}}_I(k+1), \hat{X}(k+1)]^T$

When the calculation equation for the estimated value $[\hat{\bar{X}}_I(k+1), \hat{X}(k+1)]^T$ of the state value at time t_{k+1} is changed depending on the end Ⓑ or Ⓒ as described in the equation (64) and (65), since the dead times L_B and L_C are different and change stepwise, the estimated value is not continuous each time the equation is changed. When the dead time L_B is larger than the dead time L_C, the estimated value of the equation (64) is larger than that of the equation (65) and accordingly the estimated value by the equation (11) repeatedly changes in the pulse manner. Fig. 18 shows a simulation result when the estimated value is calculated using the equations (64) and (65). In Fig. 18, the time interval of calculation t=22.5 seconds, the dead time L_B=39 seconds and L_C=37 seconds. Fig. 18 shows a control result when external heat of 8W is applied to the heater u_3 stepwise. Fig. 18(a) shows variations of thickness values y_1 to y_5 versus time, and Fig. 18(b) shows variations of amounts u_1 to u_5 of heat generated by the heaters versus time. As shown in Fig. 18(a), the thickness y_3 is once increased by the external heat, although the thickness y_3 is returned to the original set value by changing the amounts of heat generated by the heaters u_1 to u_5. However, heat generated by the heaters is repeatedly changed in the steady state and the thickness is also slightly changed repeatedly. When the position of thickness y_3 approaches the end of the film, since a difference between the dead times L_B and L_C is increased, a width of variation of heat generated by the heater is increased and variation of thickness is also larger when the estimated equations (64) and (65) are employed.

(m) Average Value $\bar{L}$ of Dead Time

In order to improve the above drawback, an average value of L_B and L_C, that is, $\bar{L}=(L_B+L_C)/2$ is employed as the dead time used in the equations (64) and (65). The equation of the estimated can be used in common for the ends Ⓑ and Ⓒ.

$$\begin{pmatrix} \hat{X}_I(k+1) \\ \\ \hat{X}(k+1) \end{pmatrix} = e^{\bar{A}\bar{L}} \begin{pmatrix} X_I(k+1) \\ \\ \hat{\omega}(k+1) \end{pmatrix} + \bar{I}(k+1) \qquad (66)$$

$$\bar{I}(k+1) = e^{\bar{A}T} \int_0^{\bar{L}-T} e^{\bar{A}\sigma} \bar{B} d\sigma \, u(k-1)$$

$$+ \int_0^T e^{\bar{A}\sigma} \bar{B} d\sigma \, u(k) \qquad (67)$$

$$\bar{L} = (L_B + L_C)/2 \quad (68)$$

(n) Simulation Example

Fig. 19 shows a simulation result when the equations (66), (67) an (68) are used as the equation of the estimated value with the same condition as in Fig. 18. Variation in the steady state of heat generated by the heater is eliminated.

(o) Means for Executing Calculation

Fig. 1 is a block diagram of a controller implementing the first invention. In the second embodiment, each of blocks is operated as follows.

(1) The detected value y(k+1) of film thickness (vector consisting of $y_1(k+1)$, $y_2(k+1)$, $y_3(k+1)$, $y_4(k+1)$ and $y_5(k+1)$) is obtained through the thickness gauge 10 and the sampler 100 at the calculation execution time $t=t_{k+1}$ of the time interval T. The sampler 100 closes for each calculation execution time $t=t_{k+1}$, that is, the sampler 100 closes each time the thickness gauge 10 reaches the end Ⓑ or Ⓒ of the film shown in Fig. 8. Further, when the thickness gauge 10 reaches the end Ⓑ or Ⓒ of the film, the gauge 10 produces the arrival end identification signal d which indicates the end which the gauge has reached.

(2) The detected value $y_3(k+1)$ of the detected film thickness value y(k+1) is supplied to a subtracter 101 which produces thickness deviation $\varepsilon(k+1)=r_3(k+1)-y_3(k+1)$ between the detected value $y_3(k+1)$ and a set value of thickness $r_3(k+1)$.

(3) The integrator 102 is supplied with the thickness deviation $\varepsilon(k+1)$ from the subtracter 101 and produces a time-integrated value of the thickness deviation from the following equation.

$$X_I(k+1) = X_I(k) + 0.5(t_{k+1} - t_k)\{\varepsilon(k) + \varepsilon(k+1)\} \quad (69)$$

where $\varepsilon(k)$ is thickness deviation at the last thickness detection time ($t=t_k$) and $X_I(k)$ is an output of the integrator 102 at $t=t_k$.

The integrator 102 includes a function of an external disturbance compensator and serves to compensate external heat varying the thickness y_3 with heat generated by the heater so that the thickness y_3 is always maintained to be a set value.

(4) When the thickness gauge reaches either end of the film, the thickness gauge produces the arrival end identification signal d. $\hat{\omega}(k+1)$ is calculated from the equations (55) and (56) or (57) and (58) in response to the identification signal d. More particularly, the past time sequence data u(k-2) and u(k-1) of heat generated by the heater stored a memory 104 together with the detected film thickness value y(k+1) are supplied to the operational calculator, which produces an estimated value $\hat{X}(t_{k+1}-L)=\hat{\omega}(k+1)$ of the state variable at time $t(_{k+1}-L)$ earlier than time t_{k+1} by the dead time L determined by the arrival end identification signal d produced by the thickness gauge.

(5) In the calculation of the first term of the right side of the equation (66), the state estimated value $[X_I(k+1), \hat{\omega}(k+1)]^T$ at time $(t_{k+1}-L)$ is multiplied by a coefficient $e^{\bar{A}\bar{L}}$ for shifting the state by the average dead time $\bar{L}$ defined by the equation (68) to obtain the state estimated value $e^{\bar{A}\bar{L}}[X_I(k+1), \hat{\omega}(k+1)]^T$ at time t_{k+1}. That is, the output $X_I(k+1)$ of the integrator 102 and the output $\hat{\omega}(k+1)$ of the operational calculator 103 are supplied to state shifter 105, which multiplies them by the coefficient for shifting the state by the average dead

time $\bar{L}$ to obtain the state estimated value at time t_{k+1}. The magnitude of the dead time $\bar{L}$ adopts the average value of the dead times for both ends of the film as described by the equation (68).

The state shift by the input u(k) applied in time domain for only the average dead time $\bar{L}$ is expressed by the second term $\bar{l}(k+1)$ of the right side of the equation (66) and correction therefor is made by a state prediction device 106.

(6) The second term $\bar{l}(k+1)$ of the right side of the equation (66) expresses an amount of shift of states for time sequence input data u(k-1) and u(k) applied to the time domain of the average dead time from time $(t_{k+1}-\bar{L})$ to time t_{k+1}. $\bar{l}(k+1)$ is calculated from the equation (67) using the average dead time $\bar{L}$. More particularly, the past time sequence data of the heat generated by the heater (in this case, two data of u(k-1) and u(k)) determined by the magnitude of the dead time $\bar{L}$ stored in the memory 104 are supplied to the state prediction device 106 and the state variation amount $\bar{l}(k+1)$ by the input u(k) from time $(t_{k+1}-\bar{L})$ to time t_{k+1}.

(7) Output $e^{A\bar{L}}[X_I(k+1), \hat{\omega}(k+1)]^T$ of the state shifter 105 and output $\bar{l}(k+1)$ of the state prediction device are added in adder 107 which produces the state estimated value $[\hat{\bar{X}}_I(k+1), \bar{X}(k+1)]^T$ at time t_{k+1}. Thus, although the operational calculator 103 can obtain only the state estimated value at time t_{k+1}-L due to the dead time L, the state estimated value at time t_{k+1} can be obtained by integration in the state shifter 105 and the state prediction device 106 for the dead time L. Influence of phase delay due to the dead time L can be eliminated by this operation.

(8) An amount u(k+1) of heat generated by the heater from time t_{k+1} to next time t_{k+2} for calculation is defined by the following equation using state feedback gain (f_1, F_2).

$$u(k+1) = -f_1\hat{\bar{X}}_I(k+1) - F_2\hat{X}(k+1) \quad (41)$$

The adder 107 supplies the state estimated value $[\hat{\bar{X}}(k+1), \hat{X}(k+1)]^T$ at time t_{k+1} to a commander 108 for heat generated by the heater. The commander 108 multiplies the state estimated value $[\hat{\bar{X}}(k+1), \hat{X}(k+1)]^T$ by the state feedback gain to define a command value of heat generated by the heater.

(9) The above control calculation is executed after the next detected value y(k+2) of film thickness is obtained from the sampler 100 at time $t=t_{k+2}$ of calculation execution when the thickness gauge is moved along the width of the film after the time period T and reaches the opposite film end.

(p) Example of Design

As a first actual example, an example of design is described in the case where transfer functions $g_1(s)$, $g_2(s)$ and $g_3(s)$ are given by the following equations:

$$g_1(s) = \frac{0.14}{S^3 + 5.5S^2 + 12.5S + 0.25} \quad (69)$$

$$g_2(s) = \frac{0.003}{S^4 + 6.4S^3 + 13.2S^2 + 1.3S + 0.009} \quad (70)$$

$$g_3(s) = \frac{0.00005}{S^5 + 6.3S^4 + 13.8S^3 + 1.6S^2 + 0.04S + 0.0002} \quad (71)$$

$u_i(t)(i=1\text{-}5)$ is variation (watt) of heat generated by the heater, and $y_i(t)(i=1\text{-}5)$ is variation (micron) of thickness of film at the position of the thickness gauge corresponding to the position of the heater. The dead time L_1 due to movement of the film and times L_1' and L_2'' required for movement of the thickness gauge from the thickness control point 3' to the film end assume the following values.

L_1 = 26 seconds
L_2' = 17 seconds
L_2'' = 7.5 seconds

Accordingly

L_B = 43 seconds
L_C = 33.5 seconds

It is assumed that the thickness control point 3' exists at the end Ⓒ of the film as shown in Fig. 8. The control calculation execution period T assumes the following value.

$$T = 22.5 \text{ seconds} \quad (72)$$

In order to design the control system, it is necessary to express the relation between the input u(t) and the output y(t) of the equation (1) and obtain the controllable and observable state equations (2) and (3). G(s) constituted of $g_1(s)$, $g_2(s)$ and $g_3(s)$ of the equations (69) to (71) can be expressed by an equation of the 77th de-

gree, while the controllable and observable equation has been found to be an equation of the 29th degree. Accordingly, the equations (2) and (3) of the 29th degree are obtained from G(s).

(1) Decision of State Feedback Gain Matrix $\bar{F}$

The state feedback gain matrix $\bar{F}$ of the equation (11) is obtained as a solution of an optimum regulator problem for the state equation (8) extended to the equation of the 30th degree on the basis of the equation (2). Since the equation (8) is a state equation of a continuous time system, the equation is changed to a discrete state function with the sampling period T=22.5 seconds and a regulator solution is applied. A proper estimation function is employed to obtain the state feedback gain matrix $\bar{F}$ and as a result the following values are obtained as main values for determining a response of control as the eigen values of the matrix $(\bar{A}-\bar{B}\bar{F})$.

0.856, 0.8119, 0.7755, 0.7618

Further, other eigen values except above are not described since the absolute value thereof is small and attenuation is fast. Since all eigen values are within a circle having a radius of 1, stable control can be attained. Since the eigen value having the slowest attenuation is 0.8560, the stabilization time Ts can be predicted as about 11 minutes from $(0876)^{30} \fallingdotseq 0.01$ with definition of control error 1% as follows.

$$Ts = Tx35 = 22x30 \text{ sec.} = 675 \text{ sec.} = 11.3 \text{ min.}$$

(2) Decision of Feedback Gain K of Operational Calculator

The feedback gain matrix K of the operational calculator of the equation (56) or (58) is obtained for the state equation (55) or (58) of the 29th degree and the output equation (54) of the fifth degree. The gain matrix K is obtaind as a solution of the optimum regulator problem so that the matrices $\{\phi_B{}^T-(C\phi_B)^T K_B{}^T\}$ and $\{\phi_C{}^T-(C\phi_C)^T K_C{}^T\}$ have a stable eigen value. For example, the discrete time of the state equation (55) defining the gain matrix K_B is $(T-L_B+L_C)=(22.5-43+33.5)=13$ seconds. As a result of obtaining the gain matrix K using a proper estimation function, the following values are obtained as main values for determining convergence of the operational calculator as eigen values of the matrix $(\phi_B-K_B C\phi_B)$.

0.9183, 0.9183, 0.9183, 0.9183, 0.9183,
0.7654, 0.7654, 0.7654, 0.7654, 0.7654,

Other eigen values except above are not described since the absolute values are small and convergence is fast. Since all the values are within a circle having a radius of 1, the estimated error can be reduced with the lapse of time. Since the eigen value having the slowest attenuation is 0.9183, the time To required for attenuation of the estimated error to an initial 1% can be predicted from $(0.9183)^{55} \fallingdotseq 0.01$ as follows.

$$T_o = (T - L_B + L_C)x55 = 13x55 \text{ sec.} = 715 \text{ sec.} = 12 \text{ min.}$$

The gain matrix K_C having the stabilization time To of 12 minutes is obtained for the matrix ϕ_C.

(q) Simulation Example 1

Fig. 20 shows an example of simulation result obtained by calculation using the gain matrices $\bar{F}$, K_B and K_C obtained above. Fig. 20(a) shows variations (variations of detected values of the thickness gauge) of five thickness values y_1 to y_5 versus time when the set value of thickness y_3 is changed stepwise by 5 micron. Fig. 20(b) shows variations of amounts u_1 to u_5 of heat generated by the heaters in the same condition as Fig. 13(a).

Since calculation is made after the execution period of 22.5 seconds of calculation after the set value of thickness has been changed, variation of heat generated by the heater occurs after 22.5 seconds from change of the set value of thickness. An amount of heat generated by the heater is maintained to the same value until 22.5 seconds elapse and the next calculation is made. The calculation is made on the basis of a newly detected value of thickness after 22.5 seconds to change an amount of heat generated by the heater. Accordingly, an amount of heat generated by the heater changes stepwise as shown in Fig. 20(b).

On the other hand, variation of the detected thickness value is detected after the lapse of the dead time L of 33.5 seconds after the amount of heat generated by the heater has been changed after the lapse of 22.5 seconds from the change of the set value. That is, variation of thickness is detected after the lapse of 22.5 + 33.5 = 56 seconds after the set value of thickness has been changed. Thickness y_3 is exactly changed to a set value and the change is substantially symmetrical to the thickness y_3. Variation of heat generated by the heater u_3 is largest, variations by the heaters u_1 and u_5 are largest next to the heater u_3, and variations of the heaters u_2 and u_4 are smallest. This reason is because interference of the heaters u_2 and u_4 to thickness y_3 is reduced. The stabilization time which is estimated by the eigen value determined by the gain matrices $\bar{F}$, K_B and K_C and is 12 minutes is supported by Fig. 20. There is no variation in heat generated by the heater at the steady state, since the equation (66) is employed to compensate the dead time instead of the equation (64)

and (65).

When the present control system is applied actually, the same calculation equation as that applied to the thickness y_3 is applied to each of thicknesses y_1, y_2, y_4, and y_5 and each command value of heat may be produced as a sum of results of the calculation equations. It will be understood that the control system considerably reduces influence of the dead time since the time required for stabilizing variation of thickness when heat generated by the heater is changed stepwise without control of heat is about 13 minutes.

(r) Simulation Example 2

The second actual example is now described with reference to Fig. 21, which shows a control result when external heat of 8 watts is applied to the heater u_3. Fig. 21(a) shows variations of thickness values y_1 to y_5 versus time, and Fig. 21(b) shows variations of heat u_1 to u_5 generated by the heaters versus time. As shown in Fig. 21(a), although the thickness y_3 is once increased by the external heat of the heater u_3, the thickness y_3 is returned to the original set value by changing the amounts of heat generated by the heaters u_1 to u_5 and the stabilization time is about 12 minutes in the same manner as Fig. 20. It is understood that variation due to the external disturbance is exactly compensated by introducing the Integrator in the present control system.

The thickness values y_2 and y_4 are once increased by influence of external heat through thermal conduction along the width of the die. The thickness values y_1 and y_5 are also influenced similarly, although the influence is small as compared with y_2 and y_4. In order to cancel the influence of such external heat, reduction of heat generated by the heater u_3 is largest, reduction by the heaters u_1 and u_5 is largest next to the heater u_3, and reduction by the heaters u_2 and u_4 is smallest. This is because the reduction in the heaters u_2 and u_4 does not influence thickness y_3 so much. When external heat is applied to the heater u_3, other thickness values y_1, y_2, y_4 and y_5 are also changed, although such interference effect can be canceled by applying the same calculation equation as that for the thickness value y_3 to each of the thickness values y_1, y_2, y_4 and y_5.

A3. Effects of the Invention

The present invention is configured as described above and accordingly has the following effects. The integrator which time-integrates a difference between a detected value of thickness of film at a predetermined position and a set value of thickness is introduced and an output of the integrator is fed back to compensate an amount of heat generated by the heater for external heat influencing thickness of the film so that thickness of the film can be always identical with the set value. Further, in order to avoid large phase delay due to the dead time, the state estimated value at time t-L earlier than the current time t by the dead time L is obtained by the operational calculator and the state estimated value at time t-L is time-integrated by the state shifter and the state prediction device during the dead time L so that the state estimated value at the current time t can be obtained to remove deterioration of control performance due to the dead time.

Claims

1. A film thickness controller which employs state equations to control an extrusion molding apparatus or a flowing type molding apparatus of film including a die having a mechanism which controls a discharge amount of molten plastic along the width of the film and a thickness gauge for detecting variation of thickness of the film after the lapse of a dead time L_1, corresponding to a time required for movement of the film between the die and the thickness gauge, comprising a subtractor (101) for producing a difference between a thickness value detected by the thickness gauge (10) in a predetermined position along the width of the film and a set value of thickness in the predetermined position, whereat said thickness gauge is reciprocated along the width of the film, characterized in that an integrator (102) for time-integrating the difference of thickness produced by said substractor (1), a memory (104) for storing past time sequence data of operation amounts of a thickness adjusting device (12b) during a dead time L equal to the sum of the dead time L_1 and a time L_2 until the thickness gauge (10) reaches an end of the film after detection of thickness in the predetermined position, an operational calculator (103) for producing the past time sequence data of operation amounts of the thickness adjusting device (12b) stored in said memory and an estimated value of state variable at a time earlier than the time when the set value of the detected thickness value of film has been inputted by the dead time L, a state shifter (105) for receiving an output of said integrator (102) and an output of said operational calculator (103) and multiplying each of said outputs of said integrator (102) and operational calculator (103) by a coefficient for shifitng the state by the dead time L to produce a state estimated value at a predetermined time, a state prediction device (106)

for receiving the past time sequence data of operation amounts of the thickness adjusting device (12b) stored in said memory (104) to produce state variation based on establishment of input from a certain time to a time after the lapse of the dead time L, and adder (107) for adding an output of said state shifter (105) and an output of said state prediction device (106) to produce the state estimated value at the predetermined time, and an operation amount commander (108) for multiplying a state estimated value at a certain time produced from said adder by a state feedback gain to produce an operation amount command value of said thickness adjusting device (12b).

2. A controller according to Claim 1, wherein said state equations are given by

$$\dot{x}(t) = Ax(t) + Bu(t) \quad (2)$$

$$y(t) = Cx(t - L) \quad (4)$$

where x is a state vector, u is an input vector in which $u(t)=[u_1(t), u_2(t), u_3(t), u_4(t), u_5(t)]^T$ (where T represents transposition), y is an output vector in which $y(t)=[y_1(t), y_2(t), y_3(t), y_4(t), y_5(t)]^T$, and the state equations (2) and (3) are controllable and observable.

3. A controller according to Claim 2, wherein said integrator (102) performs the following calculation:

$$X_I(t) = -\int_0^{t-L} C_i X(\tau)\,d\tau - \int_{t-L}^{t} C_i X(\tau)\,d\tau \quad (6)$$

where Ci is the i-th row of C matrix.

4. A controller according to Claim 3, wherein when $\omega(t)=x(t-L)$, said operational calculator (103) calculates an estimated value $\hat{X}(t-L)$ for $x(t-L)$ on the basis of the following equations for $\omega(t)$:

$$\dot{\omega}(t) = A\omega(t) + Bu(t - L) \quad (18)$$

$$y(t) = C\omega(t) \quad (19)$$

5. A controller according to Claim 4, wherein said equation (18) is the following discrete equation:

$$\omega(t_{k+1}) = e^{A(t_{k+1}-t_k)}\omega(t_k) + \int_{t_k}^{t_{k+1}} e^{A(t_{k+1}-\tau)} Bu(\tau - L)\,d\tau$$

6. A controller according to Claim 6, wherein when $\eta=t_{k+1}-\tau$, an estimated value $\hat{\omega}(k+1)$ for $\omega(t_{k+1})$ is calculated by the following equations: in the case of $2 \leqq L < T$,

$$\tilde{\omega}(k+1)=\phi\hat{\omega}(k)+\Gamma_1 u(k-3)+\Gamma_2 u(k-2) \quad (29)$$

$$\hat{\omega}(k+1)=\tilde{\omega}(k+1)+K[y(k+1)-C\tilde{\omega}(k+1)] \quad (30)$$

where K is a feedback gain matrix of said operational calculator (108), and in the case of $T<L< 2T$,

$$\tilde{\omega}(k+1)=\phi\hat{\omega}(k)+\Gamma_1 u(k-2)+\Gamma_2 u(k-1) \quad (33)$$

$$\hat{\omega}(k+1)=\tilde{\omega}(k+1)+K[y(k+1)-C\tilde{\omega}(k+1)] \quad (34)$$

where

$$\phi = e^{AT} \quad (23)$$

$$\Gamma_1 = \int_m^T e^{A\eta} B\,d\eta \quad (24)$$

$$\Gamma_2 = \int_0^m e^{A\eta} B\,d\eta \quad (25)$$

$$m = 3T - L \quad (26).$$

7. A controller according to Claim 1, wherein said controller comprises the following constituents:

(1) a detected value y(k+1) of film thickness (vector consisting of $y_1(k+1)$, $y_2(k+1)$, $y_3(k+1)$, $y_4(k+1)$ and $y_5(k+1)$) is obtained through the thickness gauge (10) and a sampler (100) at calculation execution time $t=t_{k-1}$ of the time interval T; the sampler (100) closes for each calculation execution time $t=t_{k-1}$, that is, the sampler (100) closes each time the thickness gauge 10 reaches the end Ⓑ or Ⓒ of the film shown in Fig. 8; further, when the thickness gauge (10) reaches the end Ⓑ or Ⓒ of the film, the gauge (10) produces the arrival end identification signal d which indicates the end which the thickness gauge (10) has reached;

(2) a value $y_3(k+1)$ of the detected film thickness value y(k+1) is supplied to subtracter (101) which produces thickness deviation $\varepsilon(k+1)=r_3(k+1)-y_3(k+1)$ between the detected value $y_3(k+1)$ and a set value of thickness $r_3(k+1)$;

(3) the integrator (102) is supplied with the thickness deviation ε (k+1) from the subtracter (101) and produces a time-integrated value of the thickness deviation from the following equation;

$$X_I(k+1) = X_I(k) + 0.5(t_{k-1} - t_k)\{\varepsilon(k) + \varepsilon(k+1)\} \quad (40)$$

where ε (k) is thickness deviation at the last thickness detection time ($t=t_k$) and $X_I(k)$ is an output of the integrator (102) at $t=t_k$;

the integrator (102) includes a function of an external disturbance compensator and serves to compensate external heat varying the thickness y_3 with heat generated by the heater so that the thickness y_3 is always maintained to be a set value;

(4) when the thickness gauge reaches either end of the film, the thickness gauge produces the arrival end identification signal d; ω (k+1) is calculated from the equations (29) and (30) or (33) and (34) in response to the identification signal d; more particularly, in the equations (29) and (30) for the past time sequence data of heat generated by the heater (108) stored in memory (104), u(k-3) and u(k-2) are supplied to the operational calculator (103), while in the equations (33) and (34, u(k-2) and u(k-1) together with the detected film thickness value y(k+1) are supplied to the operational calculator (103), which produces an estimated value $\hat{X}(t_{k-1}-L)=\hat{\omega}(k+1)$ of the state variable at time $t(_{k-1}-L)$ earlier than time t_{k-1} by the dead time L determined by the arrival end identification signal d produced by the thickness gauge;

(5) in the calculation of the first term of the right side of the equation (39), the state estimated value $[X_I(k+1), \hat{\omega}(k+1)]^T$ at time $(t_{k-1}-L)$ is multiplied by a coefficient $e^{\overline{A}L}$ for shifting the state by the dead time L to obtain the state estimated value $e^{\overline{A}L}[X_I(k+1), \hat{\omega}(k+1)]^T$ at time t_{k-1}; that is, the output $X_I(k+1)$ of the integrator (102) and the output $\hat{\omega}$ (k+1) of the operational calculator (103) are supplied to state shifter (105), which multiplies them by the coefficient for shifting the state by the dead time L determined by the arrival end identification signal d of the thickness gauge to obtain the state estimated value at time t_{k-1}; since the magnitude of the dead time L is different depending on the end of the film which the thickness gauge reaches, the coefficient $e^{\overline{A}L}$ is different depending on the position of the thickness gauge upon calculation execution, that is, the arrival end identification signal d of the thickness gauge ;

the state shift by the input u(k) applied in time domain for only the dead time L is expressed by the second term l(k+1) of the right side of the equation (39) and correction therefor is made by state prediction device (106);

(6) the second term l(k+1) of the right side of the equation (39) expresses an amount of shift of states for time sequence input data u(k-2), u(k-1) and u(k) applied to the time domain from time $(t_{k-1}-L)$ to time t_{k-1}; l (k+1) is calculated from the equation (37) or (38) depending on the end of the film which the thickness gauge reaches, that is, depending on the arrival end identification signal produced by the thickness gauge, more particularly, the past time-sequential data of the heat generated by the heater (in this case, three data of u(k-2), u(k-1) and u(k)) determined by the magnitude of the dead time L stored in the memory (104) are supplied to the state prediction device (106) and the state variation amount l(k+1) by the input u(k) from time $(t_{k-1}-L)$ to time t_{k-1} is produced;

(7) output $e^{\overline{A}L}[X_I(k+1), \hat{\omega}(k+1)]^T$ of the state shifter (105) and output l(k+1) of the state prediction device (106) are added in adder (107) which produces the state estimated value $[\hat{\overline{X}}_I(k+1), \hat{X}(k+1)]^T$ at time t_{k-1}; thus, although the operational calculator (103) can obtain only the state estimated value at time $t_{k-1}-L$ due to the dead time L, the state estimated value at time t_{k-1} can be obtained by integration in the state shifter (105) and the state prediction device (106) for the dead time L; influence of phase delay due to the dead time L can be eliminated by this operation;

(8) an amount u(k+1) of heat generated by the heater (12a) from time t_{k-1} to next calculation time t_{k-2} is defined by the following equation using state feedback gain (f_1, F_2) ;

$$u(k+1) = -f_1\hat{\bar{X}}_I(k+1) - F_2\hat{X}(k+1) \quad (41)$$

the adder (107) supplies the state estimated value $[\hat{\bar{X}}(k+1), \hat{X}(k+1)]^T$ at time t_{k-1} to a commander (108) for heat generated by the heater; the commander 108 multiplies the state estimated value $[\hat{\bar{X}}(k+1), \hat{X}(k+1)]^T$ by the state feedback gain to determine a command value of heat generated by the heater; and

(9) the above control calculation is executed after the next detected value y(k+2) of film thickness is obtained from the sampler (100) at time $t=t_{k-2}$ of calculation execution when the thickness gauge is moved along the width of the film after the time period T and reaches the opposite film end; where at equations (29), (30), (33), (34), (37), (38), (39) are given as follows:

$$\tilde{\omega}(k+1) = \phi\hat{\omega}(k) + \Gamma_1 u(k-3) + \Gamma_2 u(k-2) \quad (29)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K[y(k+1) - C\tilde{\omega}(k+1)] \quad (30)$$

$$\tilde{\omega}(k+1) = \phi\hat{\omega}(k) + \Gamma_1 u(k-2) + \Gamma_2 u(k-1) \quad (33)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K[y(k+1) - C\tilde{\omega}(k+1)] \quad (34)$$

$$I(k+1) = e^{\hat{A}(2T)}\int_0^{L-2T} e^{\bar{A}\sigma}\bar{B}d\sigma\, u(k-2) + e^{\bar{A}T}\int_0^T e^{\bar{A}\sigma}\bar{B}d\sigma\, u(k-1) + \int_0^T e^{\bar{A}\sigma}\bar{B}d\sigma\, u(k) \quad (37)$$

$$I(k+1) = e^{\bar{A}T}\int_0^{L-T} e^{\bar{A}\sigma}Bd\sigma\, u(k-1) + \int_0^T e^{\bar{A}\sigma}\bar{B}d\sigma\, u(k) \quad (38)$$

$$\begin{bmatrix} \hat{\bar{X}}_I(k+1) \\ \\ \hat{X}(k+1) \end{bmatrix} = e^{\bar{A}L}\begin{bmatrix} X_I(k+1) \\ \\ \hat{\omega}(k+1) \end{bmatrix} + I(k+1) \quad (39)$$

8. A controller according to Claim 7, wherein the feedback matrix F of said operation value commander (108) is selected so that all eigen values of matrix ($\bar{A}$-$\bar{B}\bar{F}$) are in a stable region.

9. A controller according to Claim 4, wherein said operational calculator (108) calculates estimated value $\hat{\omega}$ (k+1) for ω (t_{k-1}) from the following equations:

the calculation equation of the estimated value $\hat{\omega}$ (k+1) for the end Ⓑ is given by

$$\tilde{\omega}(k+1) = \phi_B\hat{\omega}(k) + \int_0^{m_B} e^{A\eta} Bd\eta\, u(k-1)$$

$$+ \int_{m_B}^{T-L_B+L_C} e^{A\eta} B d\eta \; u(k-2) \qquad (55)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K_B[y(k+1) - C\tilde{\omega}(k+1)] \qquad (56)$$

where

$$\phi_B = e^{A(T - L_B + L_C)}$$

K_B=gain matrix of the operational calculator (103),

the calculation equation of the estimated value $\hat{\omega}$ (k+1) for the end Ⓒ is given by

$$\tilde{\omega}(k+1) = \phi_C \hat{\omega}(k) + \int_0^{m_C} e^{A\eta} B d\eta \; u(k-1)$$

$$+ \int_{m_C}^{T-L_C+L_B} e^{A\eta} B d\eta \; u(k-2) \qquad (57)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K_C[y(k+1) - C\tilde{\omega}(k+1)] \qquad (58)$$

where

$$\phi_C = e^{A(T - L_C + L_B)}$$

K_C=gain matrix of the operational calculator.

10. A controller according to Claim 1, wherein said controller comprises the following constituents:

(1) the detected value y(k+1) of film thickness (vector consisting of y_1(k+1, y_2(k+1), y_3(k+1), y_4(k+1) and y_5(k+1)) is obtained through the thickness gauge (10) and sampler (100) at the calculation execution time $t=t_{k-1}$ of the time interval T; the sampler (100) closes for each calculation execution time $t=t_{k-1}$, that is, the sampler (100) closes each time the thickness gauge (10) reaches the en Ⓑ or Ⓒ of the film shown in Fig. 8; when the thickness gauge (10) reaches the end Ⓑ or Ⓒ of the film, the gauge (10) produces the arrival end identification signal d which indicates the end which the gauge has reached;

(2) a value y_3(k+1) of the detected film thickness value y(k+1) is supplied to subtracter 101 which produces thickness deviation ε (k+1)=r_3(k+1)-y_3(k+1) between the detected value y_3(k+1) and a set value of thickness r_3(k+1);

(3) the integrator (102) is supplied with the thickness deviation ε (k+1) from the subtractor (101) and produces a time-integrated value of the thickness deviation from the following equation;

$$X_I(k+1) = X_I(k) + 0.5(t_{k-1} - t_k)\{\varepsilon(k) + \varepsilon(k+1)\} \qquad (69)$$

where ε (k) is thickness deviation at the last thickness detection time ($t=t_k$) and X_I(k) is an output of the integrator (102) at $t=t_k$;

the integrator (102) includes a function of an external disturbance compensator and serves to compensate external heat varying the thickness y_3 with heat generated by the heater so that the thickness y_3 is always maintained to be a set value;

(4) when the thickness gauge reaches either end of the film, the thickness gauge produces the arrival end identification signal d. $\hat{\omega}$ (k+1) is calculated from the equations (55) and (56) or (57) and (58) in response to the identification signal d; the past time sequence data u(k-2) and u(k-1) of heat generated by the heater stored a memory (104) together with the detected film thickness value y(k+1) are supplied to the operational calculator, which produces an estimated value $\hat{X}(t_{k-1}\text{-}L)=\hat{\omega}$ (k+1) of the state variable at time $t(_{k-1}$-L) earlier than time t_{k-1} by the dead time L determined by the arrival end identification signal d produced by the thickness gauge;

(5) in the calculation of the first term of the right side of the equation (66), the state estimated value $[X_I(k+1), \hat{\omega}(k+1)]^T$ at time (t_{k-1}-L) is multiplied by a coefficient $e^{\bar{A}\bar{L}}$ for shifting the state by the average dead time $\bar{L}$ defined by the equation (68) to obtain the state estimated value $e^{\bar{A}\bar{L}}[X_I(k+1), \hat{\omega}(k+1)]^T$ at

time t_{k-1}; the output $X_1(k+1)$ of the integrator (102) and the output $\hat{\omega}$ (k+1) of the operational calculator (103) are supplied to state shifter (105), which multiplies them by the coefficient for shifting the state by the average dead time $\bar{L}$ to obtain the state estimated value at time t_{k-1}; the magnitude of the dead time $\bar{L}$ adopts the average value of the dead times for both ends of the film as described by the equation (68);

the state shift by the input u(k) applied in time domain for only the average dead time $\bar{L}$ is expressed by the second term $I(k+1)$ of the right side of the equation (66) and correction therefor is made by state prediction device 106;

(6) the second term $I(k+1)$ of the right side of the equation (66) expresses an amount of shift of states for time sequence input data u(k-1) and u(k) applied to the time domain of the average dead time $\bar{L}$ from time $(t_{k-1}-\bar{L})$ to time t_{k-1}; $I(k+1)$ is calculated from the equation (67) using the average dead time $\bar{L}$; the past time sequence data of the heat generated by the heater (in this case, two data of u(k-1) and u(k)) determined by the magnitude of the dead time $\bar{L}$ stored in the memory (104) are supplied to the state prediction device (106) and the state variation amount $I(k+1)$ by the input u(k) from time $(t_{k-1}-\bar{L})$ to time t_{k-1};

(7) output $e^{A\bar{L}}[X_I(k+1), \hat{\omega}(k+1)]^T$ of the state shifter 105 and output $I(k+1)$ of the state prediction device are added in adder 107 which produces the state estimated value $[\hat{\bar{X}}_I(k+1), \bar{X}(k+1)]^T$ at time t_{k-1}; although the operational calculator (103) can obtain only the state estimated value at time t_{k-1}-L due to the dead time L; the state estimated value at time t_{k-1} can be obtained by integration in the state shifter (105) and the state prediction device (106) for the dead time $\bar{L}$; influence of phase delay due to the dead time L can be eliminated by this operation;

(8) an amount u(k+1) of heat generated by the heater from time t_{k-1} to next calculation time t_{k-2} is defined by the following equation using state feedback gain (f_1, F_2);

$$u(k+1) = -f_1\hat{\bar{X}}_I(k+1) - F_2\hat{X}(k+1) \quad (41)$$

the adder (107) supplies the state estimated value $[\hat{\bar{X}}(k+1), \hat{X}(k+1)]^T$ at time t_{k-1} to a commander 108 for heat generated by the heater; the commander (108) multiplies the state estimated value $[\hat{\bar{X}}(k+1), \hat{X}(k+1)]^T$ by the state feedback gain to define a command value of heat generated by the heater; and

(9) the above calculation is executed after the next detected value y(k+2) of film thickness is obtained from the sampler (100) at time $t=t_{k-2}$ of calculation execution when the thickness gauge is moved along the width of the film after the time period T and reaches the opposite film end, where at equations (55), (56), (57), (58), (66), (67), (68) are given as follows :

$$\tilde{\omega}(k+1) = \phi_B\hat{\omega}(k) + \int_0^{m_B} e^{A\eta}Bd\eta\, u(k-1) + \int_{m_B}^{T-L_B+L_C} e^{A\eta}Bd\eta\, u(k-2) \quad (55)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K_B[y(k+1) - C\tilde{\omega}(k+1)] \quad (56)$$

where

$$\phi_B = e^{A(T - L_B + L_C)}$$

K_B=gain matrix of the operational calculator

$$\tilde{\omega}(k+1) = \phi_C\hat{\omega}(k) + \int_0^{m_C} e^{A\eta}Bd\eta\, u(k-1)$$

$$+ \int_{m_C}^{T-L_C+L_B} e^{A\eta}Bd\eta\, u(k-2) \quad (57)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K_C[y(k+1) - C\tilde{\omega}(k+1)] \quad (58)$$

where

$$\phi_C = e^{A(T - L_C + L_B)}$$

K_C=gain matrix of the operational calculator.

$$\begin{bmatrix} \hat{X}_I(k+1) \\ \\ \hat{X}(k+1) \end{bmatrix} = e^{\bar{\Lambda}\bar{L}} \begin{bmatrix} X_I(k+1) \\ \\ \hat{\omega}(k+1) \end{bmatrix} + \bar{I}(k+1) \qquad (66)$$

$$\bar{I}(k+1) = e^{\bar{\Lambda}\bar{T}} \int_0^{\bar{L}-T} e^{\bar{\Lambda}\sigma} \bar{B} d\sigma \; u(k-1) + \int_0^{T} e^{\bar{\Lambda}\sigma} \bar{B} d\sigma \; u(k) \qquad (67)$$

$$\bar{L} = (L_B + L_C)/2 \qquad (68)$$

Patentansprüche

1. Vorrichtung zur Kontrolle der Dicke eines Filmes, welche Zustandsgleichungen zur Steuerung eines Extrusions-Spritzgießgerätes oder eines Preßspritzgerätes für einen Film verwendet, mit einer Gußform, welche einen Mechanismus aufweist, der die Ausflußmenge an geschmolzenem Plastik entlang der Filmbreite steuert, und einer Dicke-Meßeinrichtung zur Erfassung der Filmdickenabweichung nach Verstreichen einer Totzeit L_1, die einer für die Bewegung des Filmes zwischen der Gußform und der Dicke-Meßeinrichtung erforderlichen Zeit enspricht, und mit einer Subtrahierschaltung (101) zur Erzeugung einer Differenz zwischen einem durch die Dicke-Meßeinrichtung (10) in einer vorbestimmten Position entlang der Filmbreite erfaßten Dicke-Wert und einem Dicke-Soll-Wert in der vorbestimmten Position, wobei die Dicke-Meßeinrichtung entlang der Filmbreite hin- und herbewegt wird,
   dadurch gekennzeichnet,
   daß sie einen Integrator (102) zur Zeitintegration der durch die Subtrahierschaltung (101) erzeugten Dicken-Differenz aufweist,
   einen Speicher (104) zur Speicherung vergangener Datensequenzen der Betriebsmengen einer Dicken-Einstelleinrichtung (12b) während einer Totzeit L, welche gleich der Summe ist aus der Totzeit L_1 und einer Zeit L_2, bis die Dicke-Meßeinrichtung (10) ein Ende des Filmes nach dem Erfassen der Dicke in der vorbestimmten Position erreicht,
   einen Betriebsrechner (103) zur Erzeugung der vergangenen Datensequenz der Betriebsmengen der Dicke-Einstelleinrichtung (12b), welche in dem Speicher gespeichert sind,
   und eines Schätzwertes der Zustandsvariablen zu einem Zeitpunkt, welcher vor dem Zeitpunkt liegt, an dem der Sollwert des erfassten Filmdickewertes mit der Totzeit L eingegeben wurde,
   einen Zustandswechsler (105) für den Empfang eines Ausgangsignals des Integrators (102) und eines Ausgangssignals des Betriebsrechners (103) zur Multiplikation der beiden Ausgangssignale des Integrators (102) und des Betriebsrechners (103) mit einem Koeffizienten zum Zustandswechsel bei der Totzeit L zur Erzeugung eines Zustands-Schätzwertes bei einer vorbestimmten Zeit,
   eine Zustandsvorhersage-Einrichtung (106) für den Empfang der vergangenen Datensequenz der Betriebsmengen der Dikkeneinstell-Einrichtung (12b), welche in dem Speicher (104) gespeichert ist, zur Erzeugung einer Zustandsabweichung basierend auf der Ermittlung des Eingangs ab einem gewissen Zeitpunkt bis hin zu einem Zeitpunkt nach Verstreichen der Totzeit L,
   einer Addiereinrichtung (107) zur Addition des Ausgangs des Zustandswechslers (105) und des Ausgangs der Zustandsvorhersage-Einrichtung (106) zur Erzeugung des Zustands-Schätzwertes zur vorbestimmten Zeit,
   und eine Betriebsmengen-Befehlseinrichtung (108) zur Multiplikation des von der Addiereinrichtung zu einem bestimmten Zeitpunkt erzeugten Zustands-Schätzwertes mit einer Zustands-Rückkopplungs-Verstärkung zur Erzeugung eines Betriebsmengen-Befehlwertes für die Dickeneinstell-Einrichtung (12b).

2. Vorrichtung nach Anspruch 1 bei der die Zustandsgleichungen gegeben sind durch

$$\dot{x}(t) = Ax(t) + Bu(t) \quad (2)$$

$$y(t) = Cx(t-L) \quad (4)$$

wobei x ein Zustandsvektor, u ein Eingangsvektor ist mit $u(t) = [u_1(t), u_2(t), u_3(t), u_4(t), u_5(t)]^T$ (wobei T für Transposition steht), y ein Ausgansvektor ist mit $y(t) = [y_1(t), y_2(t), y_3(t), y_4(t), y_5(t)]^T$, und die Zustandsgleichung (2) und (3) steuerbar und beobachtbar sind.

3. Vorrichtung nach Anspruch 3 bei der der Integrator (102) folgende Berechnungen ausführt:

$$\bar{X}_I(t) = -\int_0^{t-L} C_I X(\tau)\,d\tau - \int_{t-L}^{t} C_I X(\tau)\,d\tau \qquad (6)$$

wobei C_I die i-Reihe der C Matrix ist.

4. Vorrichtung nach Anspruch 3 bei der wenn $\omega(t) = x(t-L)$, der Betriebsrechner (103) einen Schätzwert $\hat{X}(t-L)$ für $x(t-L)$ auf der Basis der folgenden Gleichungen für $\omega(t)$ berechnet:

$$\dot{\omega}(t) = A\omega(t) + Bu(t-L) \quad (18)$$

$$y(t) = C\omega(t) \quad (19)$$

5. Vorrichtung nach Anspruch 4 bei der die Gleichung (18) die folgende diskrete Gleichung ist:

$$\omega(t_{k+1}) = e^{A(t_{k+1}-t_k)}\omega(t_k) + \int_{t_k}^{t_{k+1}} e^{A(t_{k+1}-\tau)} Bu(\tau - L)\,d\tau$$

6. Vorrichtung nach Anspruch 6 bei der, $\eta = t_{k+1} - \tau$ wenn ein Schätzwert $\hat{\omega}(k+1)$ für $\omega(t_{k+1})$ durch die folgenden Gleichungen berechnet wird:
Im Fall daß $2 \leqq L < T$,

$$\tilde{\omega}(k+1) = \phi\,\hat{\omega}(k) + \Gamma_1 u(k-3) + \Gamma_2 u(k-2) \qquad (29)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K[y(k+1) - C\tilde{\omega}(k+1)] \qquad (30)$$

wobei K eine Rückkopplungsverstärkungs-Matrix des Betriebsrechners (108) ist, und für den Fall, daß $T < L < 2T$

$$\tilde{\omega}(k+1) = \phi\,\hat{\omega}(k) + \Gamma_1 u(k-2) + \Gamma_2 u(k-1) \qquad (33)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K[y(k+1) - C\tilde{\omega}(k+1)] \qquad (34)$$

wobei

$$\phi = e^{AT} \quad (23)$$

$$\Gamma_1 = \int_m^T e^{A\eta} B\,d\eta \qquad (24)$$

$$\Gamma_2 = \int_0^m e^{A\eta} B\,d\eta \qquad (25)$$

$$m = 3T - L \quad (26)$$

7. Vorrichtung nach Anspruch 1, bei der die Kontrollvorrichtung folgende Bestandteile aufweist:

(1) ein erfaßter Wert $Y(k+1)$ der Filmdicke (Vektor der bestehend aus $y_1(k+1)$, $y_2(k+1)$, $y_3(k+1)$, $y_4(k+1)$ und $y_5(k+1)$) wird erhalten durch die Dicken-Meßeinrichtung (10) und einen Abtaster (100) bei der Berechnungsausführungszeit $t=t_{k+1}$ des Zeitintervalls T; der Abtaster (100) schließt für jede Berechnungsausführungszeit $t=t_{k+1}$, d.h. der Abtaster (100) schließt jedes Mal, wenn die Dickemeßeinrichtung (10) das Ende Ⓑ oder Ⓒ des Filmes, wie in Figur 8 gezeigt, erreicht; ferner, wenn die Dickemeßeinrichtung (10) das Ende Ⓑ oder Ⓒ des Filmes erreicht, erzeugt die Dickemeßeinrichtung (10) das Ende - erreicht -Idendifikationssignal d, welches das Ende, das die Dickemeßeinrichtung (10) erreicht hat, anzeigt:
(2) ein Wert $y_3(k+1)$ des erfaßten Filmdickewertes $y(k+1)$ wird einer Subtrahierschaltung (101) zugeführt, welche die Dickenabweichung $\varepsilon(k+1) = r_3(k+1) - y_3(k+1)$ zwischen dem erfaßten Wert $y_3(k+1)$ und einem Sollwert der Dicke $r_3(k+1)$ liefert;
(3) der Integrator (102) erhält die Dickenabweichung ε (k+1) von der Subtrahierschaltung (101) und erzeugt einen zeitintegrierten Wert der Dickenabweichung aus der folgenden Gleichung:

$$X_I(k + 1) = X_I(k) + 0.5(t_{k-1} - t_k) \{\varepsilon (k) + \varepsilon (k + 1)\} \quad (40)$$

wobei ε (k) die Dickenabweichung zum letzten Dickenerfaßungszeitpunkt ($t=t_k$) und $X_1(k)$ der Ausgang des Integrators (102) bei $t=t_k$ ist;
Der Integrator (102) umfaßt eine Funktion für den Ausgleich externer Störungen und dient zum Ausgleich externer Hitze, welche die Dicke y_3 verändert, mit Hitze, welche durch den Erhitzer erzeugt wird, so daß die Dicke y_3 immer bei einem Sollwert gehalten wird;
(4) wenn die Dickemeßeinrichtung ein Ende des Filmes erreicht, erzeugt die Dickemeßeinrichtung das Ende-erreicht-Idendifikationssignal d; $\omega(k+1)$ wird aus den Gleichungen (29) und (30) oder (33) und (34) in Reaktion auf das Idendifikationssignal d berechnet; genauer gesagt wird in den Gleichungen (29) und (30) für die vergangene Datensequenz der Hitze, welche durch den Erhitzer erzeugt und in dem Speicher (104) gespeichert sind, u(k-3) und u(k-2) dem Betriebsrechner (103) zugeführt, während in den Gleichungen (33) und (34) u(k-2) und u(k-1) zusammen mit dem erfaßten Filmdickewert y(k+1) dem Betriebsrechner (103) zugeführt werden, welcher einen Schätzwert $\hat{X}(t_{k+1} - L)=\hat{\omega}(k+1)$ der Zustandsvariable (t_{k+1} - L) erzeugt, welcher vor dem Zeitpunkt t_{k+1} um die Totzeit L liegt, welche durch das Ende-erreicht-Idendifikationssignal d bestimmt wird, daß durch die Dickemeßeinrichtung erzeugt wird;
(5) bei der Berechnung des ersten Terms der rechten Seite der Gleichung (39) wird der Zustandsschätzwert $[x_I(k+1), \hat{\omega}(k+1)]^T$ zum Zeitpunkt (t_{k+1}-L) mit einem Koeffizienten $e^{\overline{AL}}$ zum Wechsel des Zustandes bei der Totzeit L multipliziert, um einen Zustandsschätzwert zum Zeitpunkt t_{k+1} zu erhalten; d.h. der Ausgang $X_I(k+1)$ des Integrators (102) und der Ausgange $\hat{\omega}(k+1)$ des Betriebsrechners (103) werden dem Zustandswechsler (105) zugeführt, welcher sie mit dem Koeffizienten multipliziert zum Wechsel des Zustands nach der Todzeit L, welche durch des Ende-erreicht-Idendifikationssignal d der Dickemeßeinrichtung bestimmt wird, um den Zustandsschätzwert zum Zeitpunkt t_{k+1} zu erhalten; da die Größe der Totzeit L in Abhängigkeit des von der Dickemeßeinrichtung erreichten Filmendes unterschiedlich ist, ist der Koeffizient $e^{\overline{AL}}$ in Abhängigkeit der Position der Dickemeßeinrichtung bei der Berechnungsausführung unterschiedlich, d.h. in Abhängigkeit von dem Ende-erreicht-Idendifikationssignal d der Meßeinrichtung;
der Zustandswechsel durch den Eingang u(k), welcher in der Zeitdomäne nur für die Totzeit L angelegt wird, wird durch den zweiten Term I(k+1) der rechten Seite der Gleichung (39) ausgedrückt und die Korrektur wird durch die Zustandsvorhersageeinrichtung (106) durchgeführt;
(6) der zweite Term I(k+1) der rechten Seite der Gleichung (39) drückt einen Betrag des Zustandswechsels für die Zeiteingabedatensequenz u(k-2),u(k-1) und u(k) aus, die für das Zeitintervall vom Zeitpunkt (t_{k+1}-L) bis zum Zeitpunkt t_{k+1} anliegen; I(k+1) wird aus der Gleichung (37) oder (38) in Abhängigkeit des Filmendes, welche die Dickemeßeinrichtung erreicht, berechnet, d.h. in Abhängigkeit des Ende-erreicht-Idendifikationssignals, welches durch die Dickemeßeinrichtung erzeugt wird, genauer gesagt werden die vergangenen zeitsequentiellen Daten der Hitze, welche durch den Erhitzer erzeugt werden (in diesein Falle die Daten u(k-2), u(k-1) und u(k)), welche die durch die Größe der in dem Speicher (104) gespeicherten Totzeit L bestimmt werden, der Zustandsvorhersageeinrichtung (106) zugeführt und der Zustandsveränderungsbetrag I(k+1) wird aus dem Eingang u(k) vom Zeitpunkt (t_{k+1}-L) bis zum Zeitpunkt t_{k+1} erzeugt;
(7) der Ausgang $e^{\overline{AL}}[x_I(k+1),\hat{\omega}(k+1)]^T$ des Zustandswechslers (105) und der Ausgang I(k+1) der Zustandsvorhersageeinrichtung (106) werden in der Addiereinrichtung (107) addiert, welche den Zustandsschätzwert $[\hat{\overline{X}}_I(k+1), \hat{X}(k+1)]^T$ zum Zeitpunkt t_{k+1} erzeugt; auf diese Weise kann der Zustandschätzwert zum Zeitpunkt t_{k+1} durch Integration in dem Zustandwechsler (105) und der Zustandsvorhersageeihrichtung (106) für die Totzeit L erhalten werden, obwohl der Betriebsrechner

(103) nur den Zustandsschätzwert zum Zeitpunkt t_{k+1}-L infolge der Totzeit L erhalten kann; der Einfluß der Phasenverzögerung infolge der Totzeit L kann durch diese Operation eliminiert werden;
(8) der Betrag u(k+1) der Hitze, welche durch den Erhitzer (12a) vom Zeitpunkt t_{k+1} bis zum nächsten Berechnungszeitpunkt t_{k+2} erzeugt wird, wird durch die folgende Gleichung unter Verwendung der Zustandrückkopplungsverstärkung (f_f, F_2) bestimmt:

$$u(k+1) = -f_1 \hat{\bar{X}}_I(k+1) - F_2 \hat{X}(k+1) \quad (41)$$

Die Addiereinrichtung (107) gibt den Zustandsschätzwert $[\hat{\bar{X}}(k+1), \hat{X}(k+1)]^T$ zum Zeitpunkt t_{k+1} an die Befehlseinrichtung (108) für die durch den Erhitzer erzeugte Hitze ab; die Befehlseinrichtung (108) multipliziert den Zustandsschätzwert $[\hat{\bar{X}}(k+1), \hat{X}(k+1)]^T$ mit der Zustandsrückkopplungsverstärkung zur Bestimmung eines Befehlswertes der durch den Erhitzer erzeugten Hitze; und
(9) die obige Kontrollberechnung wird, nachdem der nächste erfaßte Wert y(k+2) der Filmdicke von dem Abtaster (100) zum Zeitpunkt $t=t_{k+2}$ der Berechnungsausführung erhalten wurde, ausgeführt, wenn die Dickemeßeinrichtung entlang der Filmbreite nach Ablauf der Zeitperiode T bewegt wird und das entgegengesetze Ende erreicht, wobei die Gleichungen (29),(30),(33),(34),(37),(38),(39), gegeben sind, wie folgt:

$$\tilde{\omega}(k+1) = \phi\,\hat{\omega}(k) + \Gamma_1 u(k-3) + \Gamma_2 u(k-2) \quad (29)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K[y(k+1) - C\tilde{\omega}(k+1)] \quad (30)$$

$$\tilde{\omega}(k+1) = \phi\,\hat{\omega}(k) + \Gamma_1 u(k-2) + \Gamma_2 u(k-1) \quad (33)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K[y(k+1) - C\tilde{\omega}(k+1)] \quad (34)$$

$$I(k+1) = e^{\bar{A}(2T)} \int_0^{L-2T} e^{\bar{A}\sigma} \bar{B}\, d\sigma\; u(k-2) + e^{\bar{A}T} \int_0^{T} e^{\bar{A}\sigma} \bar{B}\, d\sigma\; u(k-1) + \int_0^{T} e^{\bar{A}\sigma} \bar{B}\, d\sigma\; u(k) \quad (37)$$

$$I(k+1) = e^{\bar{A}T} \int_0^{L-T} e^{\bar{A}\sigma} B\, d\sigma\; u(k-1) + \int_0^{T} e^{\bar{A}\sigma} \bar{B}\, d\sigma\; u(k) \quad (38)$$

$$\begin{pmatrix} \hat{X}_I(k+1) \\ \hat{X}(k+1) \end{pmatrix} = e^{\bar{A}L} \begin{pmatrix} X_I(k+1) \\ \hat{\omega}(k+1) \end{pmatrix} + I(k+1) \quad (39)$$

8. Vorrichtung nach Anspruch 7, bei der die Rückkopplungsmatrix F der Betriebsmengenbefehlseinrichtung (108) so ausgewählt wird, daß alle Eigenwerte der Matrix $(\bar{A}-\bar{B}F)$ in einem stabilen Bereich liegen.

9. Vorrichtung nach Anspruch 4, bei der der Betriebsrechner (108) einen Schätzwert $\hat{\omega}(k+1)$ für $\omega(t_{k+1})$ aus den folgenden Gleichungen berechnet:
Die Berechnungsgleichung für den Schätzwert $\hat{\omega}(k+1)$ für das Ende Ⓑ ist gegeben durch

$$\tilde{\omega}(k+1) = \phi_B \hat{\omega}(k) + \int_0^{m_B} e^{A\eta} B d\eta \; u(k-1)$$

$$+ \int_{m_B}^{T-L_B+L_C} e^{A\eta} B d\eta \; u(k-2) \qquad (55)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K_B[y(k+1) - C\tilde{\omega}(k+1)] \qquad (56)$$

wobei

$$\phi_B = e^{A(T - L_B + L_C)}$$

K_B= die Verstärkungsmatrix des Betriebsrechners (103), und die Rechnungsgleichung für den Schätzwert $\hat{\omega}(k+1)$ für das Ende C gegeben ist durch

$$\tilde{\omega}(k+1) = \phi_C \hat{\omega}(k) + \int_0^{m_C} e^{A\eta} B d\eta \; u(k-1)$$

$$+ \int_{m_C}^{T-L_C+L_B} e^{A\eta} B d\eta \; u(k-2) \qquad (57)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K_C[y(k+1) - C\tilde{\omega}(k+1)] \qquad (58)$$

wobei ** 16

$$\phi_C = e^{A(T - L_C + L_B)}$$

K_C= die Verstärungsmatrix des Betriebsrechners ist.

10. Vorrichtung nach Anspruch 1, bei der die Kontrolleinrichtung die folgenden Bestandteile aufweist:

(1) der erfaßte Wert y(k+1) der Filmdicke (ein aus $y_1(k+1)$, $y_2(k+1)$, $y_3(k+1)$, $y_4(k+1)$ und $y_5(k+1)$ bestehender Vektor) wird durch die Dickemeßeinrichtung (10) und den Abtaster (100) bei der Berechnungsausführungszeit $t=t_{k+1}$ des Zeitintervalles T erhalten; der Abtaster (100) schließt bei jeder Berechnungsausführungszeit $t=t_{k+1}$, d.h. der Abtaster (100) schließt jedesmal, wenn die Dickemeßeinrichtung (10) das Ende Ⓑ oder Ⓒ des Filmes, wie im Figur 8 gezeigt, erreicht; wenn die Dickemeßeinrichtung (10) das Ende Ⓑ oder Ⓒ des Filmes erreicht, erzeugt die Dickemeßeinrichtung (10) das Ende-erreicht Idendifikationssignal d, welches das durch die Meßeinrichtung erreichte Ende anzeigt;

(2) ein Wert $y_3(k+1)$ des erfaßten Filmdickewertes y(k+1) wird der Subrahiereinrichtung (101) zugeführt, welches die Dickenabweichung $\varepsilon(k+1) = r_3(k+1)-y_3(k+1)$ zwischen dem erfaßten Wert $y_3(k+1)$ und einem Dickesollwert $r_3(k+1)$ erzeugt;

(3) dem Integrator wird die Dickenabweichung $\varepsilon(k+1)$ aus der Subtrahierschaltung (101) zugeführt und er erzeugt einen zeitintegrierten Wert der Dickenabweichung aus der folgenden Gleichung;

$$X_I(k+1) = X_I(k) + 0.5(t_{k-1} - t_k)\{\varepsilon(k) + \varepsilon(k+1)\} \qquad (69)$$

wobei $\varepsilon(k)$ die Dickenabweichung bei der letzten Dickenerfassungszeit $(t=t_k)$ und $X_I(k)$ ein Ausgang des Integrators (102) bei $t=t_k$ ist;

der Integrator (102) umfaßt eine Funktion eines Kompensators externer Störungen und dient zum Ausgleich externer Hitze, welche die Dicke y_3 verändert, durch von dem Erhitzer erzeugte Hitze, so daß die Dicke y_3 immer bei einem Soll-Wert gehalten wird;

(4) wenn eine Dickemeßeinrichtung ein Ende des Filmes erreicht, erzeugt die Dickemeßeinrichtung das Ende-erreicht Idendifikationssignal d. $\hat{\omega}$ (k+1) wird aus den Gleichungen (55) und (56) und (57) und (58) in Reaktion auf das Idendifikationssignal d berechnet; die vergangene Datensequenz u(k-2) und u(k) der durch den Erhitzer erzeugten Hitze, welche in einem Speicher (104) zusammen mit dem erfaßten Filmdickewert y(k+1) gespeichert ist, wird dem Betriebsrechner zugeführt welcher einen Schätzwert von $\hat{X}(t_{k+1}-L) = \hat{\omega}(k+1)$ der Zustandsvariablen zum Zeitpunkt $t_{(k+1}-L)$ erzeugt, welcher vor dem Zeitpunkt t_{k+1} um die Totzeit L liegt, welche durch das Ende-erreicht Idendifikationssignal d bestimmt wird, das durch die Dikkemeßeinrichtung erzeugt wird;

(5) bei der Berechnung des ersten Terms auf der rechten Seite der Gleichung (66) wird der Zustandsschätzwert $[x_I(k+1), \hat{\omega}(k+1)]^T$ zum Zeitpunkt $(t_{k+1}-L)$ mit einem Koeffizienten $e^{\bar{A}\bar{L}}$ zum Wechsel des Zustands bei der Durchschnittstotzeit $\bar{L}$ multipliziert, welche durch die Gleichung (68) bestimmt wird, um

den Zustandsschätzwert $e^{A\bar{L}}[X_I(k+1), \hat{\omega}(k+1)]^T$ zum Zeitpunkt t_{k+1} zu erhalten; der Ausgang $X_I(k+1)$ des Integrators (102) und der Ausgang $\hat{\omega}(k+1)$ des Betriebsrechners (103) werden dem Zustandswechsler (105) zugeführt, welcher sie mit dem Koeffizienten zum Wechsel des Zustands bei der Durchschnittstotzeit $\bar{L}$ multipliziert, um den Zustandsschätzwert zum Zeitpunkt t_{k+1}. zu erhalten; die Größe der Totzeit $\bar{L}$ nimmt den durch-schnittlichen Wert der Totzeiten für beide Enden des Filmes an, wie durch die Gleichung (68) beschrieben ist; der Zustandwechsel durch den Eingang u(k), welcher in der Zeitdomäne lediglich für die Durchschnittstotzeit $\bar{L}$ angelegt wird, wird durch den zweiten Term $I(k+1)$ auf der rechten Seite der Gleichung (66) ausgedrückt und eine Korrektur wird daher durch die Zustandsvorhersageeinrichtung (106) ausgeführt;

(6) der zweite Term $\bar{I}(k+1)$ auf der rechten Seite der Gleichung (66) drückt einen Betrag des Zustandswechsels für die Zeiteingabedatensequenz u(k-1) und u(k) aus, welche der Zeitdomäne für die Durchschnittstotzeit $\bar{L}$ von Zeitpunkt $(t_{k+1}-\bar{L})$ bis zum Zeitpunkt t_{k+1} angelegt werden; $\bar{I}(k+1)$ wird aus der Gleichung (67) unter Verwendung der Durchschnittstotzeit $\bar{L}$ berechnet; die vergangene Datensequenz der durch den Erhitzer erzeugten Hitze (in diesem Falle zwei Daten u(k-1) und u(k)), welche durch die Größe der in dem Speicher (104) gespeicherten Totzeit $\bar{L}$ bestimmt werden, werden der Zustandsvorhersageeinrichtung (106) zugeführt und der Zustandsendebetrag $I(k+1)$ durch den Eingang u(k) vom Zeitpunkt $(t_{k+1}-\bar{L})$ bis zum Zeitpunkt.

(7) der Ausgang $e^{A\bar{L}}[X_I(k+1),\hat{\omega}(k+1)]^T$ des Zustandswechslers (105) und der Ausgang $I(k+1)$ Zustandsvorhersageeinrichtung werden in der Addiereinrichtung (107) addiert, welche den Zustandsschätzwert $[\hat{\bar{X}}_I(k+1), \bar{X}(k+1)]^T$ zum Zeitpunkt t_{k+1} erzeut; obwohl der Betriebsrechner (103) lediglich den Zustandsschätzwert zum Zeitpunkt t_{k+1}-L infolge der Totzeit $\bar{L}$ erhalten kann, kann der Zustandsschätzwert zum Zeitpunkt t_{k+1} durch Integration in dem Zustandswechsler (105) und der Zustandsvorhersageeinrichtung (106) für die Totzeit L erhalten werden; der Einfluß der Phasenverzögerung infolge der Totzeit L kann durch diese Operation eliminiert werden;

(8) ein Betrag u(k+1) der durch den Erhitzer erzeugten Hitze vom Zeitpunkt t_{k+1} bis hin zum nächsten Berechnungszeitpunkt t_{k+2} wird durch die folgende Gleichung unter Verwendung der Zustandsrückkopplungsverstärkung (f_1, F_2) bestimmt:

$$u(k+1) = -f_1\hat{\bar{X}}_I(k+1) - F_2\hat{X}(k+1) \quad (41)$$

die Addiereinrichtung (107) gibt den Zustandsschätzwert $[\hat{\bar{X}}(k+1), \hat{X}(k+1)]^T$ zum Zeitpunkt t_{k+1} an die Befehlseinrichtung (108) für die durch den Erhitzer erzeugte Hitze ab; die Befehlseinrichtung (108) multipliziert den Zustandsschätzwert $[\hat{\bar{X}}(k+1), \hat{X}(k+1)]^T$ mit der Zustandsrückkopplungsverstärkung zur Bestimmung eines Befehlswertes der durch den Erhitzer erzeugten Hitze; und

(9) die obige Berechnung wird ausgeführt nachdem der nächste erfaßte Wert y(k+2) der Filmdicke von dem Abtaster (100) zum Zeitpunkt $t=t_{k+2}$ der Berechnungsausführung erhalten wird, wenn die Dickemeßeinrichtung nach der Zeitperiode T entlang der Breite des Filmes bewegt wird und das entgegengesetzte Filmende erreicht, wobei die Gleichungen (55), (56),(57), (58), (66), (67),(68), gegeben sind folgt:

$$\tilde{\omega}(k+1) = \phi_B\hat{\omega}(k) + \int_0^{m_B} e^{A\eta}Bd\eta\, u(k-1) + \int_{m_B}^{T-L_B+L_C} e^{A\eta}Bd\eta\, u(k-2) \quad (55)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K_B[y(k+1)-C\tilde{\omega}(k+1)] \quad (56)$$

wobei

$$\phi_B = e^{A(T - L_B + L_C)}$$

K_B= die Verstärkungsnatrix des Betriebsrechners ist.

$$\tilde{\omega}(k+1) = \phi_c \hat{\omega}(k) + \int_0^{m_c} e^{A\eta} B d\eta \; u(k-1)$$
$$+ \int_{m_c}^{T-L_c+L_B} e^{A\eta} B d\eta \; u(k-2) \qquad (57)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K_c[y(k+1) - C\tilde{\omega}(k+1)] \qquad (58)$$

wobei

$$\phi_C = e^{A(T - L_C + L_B)}$$

K_C= die Verstärkungsmatrix des Betriebsrechners ist.

$$\begin{bmatrix} \hat{X}_1(k+1) \\ \hat{X}(k+1) \end{bmatrix} = e^{\bar{A}\bar{L}} \begin{bmatrix} X_1(k+1) \\ \hat{\omega}(k+1) \end{bmatrix} + \bar{I}(k+1) \qquad (66)$$

$$\bar{I}(k+1) = e^{\bar{A}\bar{T}} \int_0^{\bar{L}-T} e^{\bar{A}\sigma} \bar{B} d\sigma \; u(k-1)$$
$$+ \int_0^{T} e^{\bar{A}\sigma} \bar{B} d\sigma \; u(k) \qquad (67)$$

$$\bar{L} = (L_B + L_C)/2 \qquad (68)$$

Revendications

1. Dispositif de commande de l'épaisseur d'une couche qui utilise des équations d'état pour commander un appareil de moulage par extrusion ou un appareil de moulage par écoulement de couches comportant une filière ayant un mécanisme qui commande, dans la largeur de la couche, un débit de plastique fondu, et une jauge d'épaisseur pour détecter une variation d'épaisseur de la couche après l'écoulement d'un temps mort L_1 correspondant au temps nécessaire au mouvement de la couche entre la filière et la jauge d'épaisseur, comprenant un soustracteur (101) pour produire une différence entre une valeur d'épaisseur détectée par la jauge d'épaisseur (10) dans une position prédéterminée dans la largeur de la couche et une valeur de consigne d'épaisseur dans la position prédéterminée, où ladite jauge d'épaisseur se déplace dans un mouvement alternatif dans la largeur de la couche, caractérisé par un intégrateur (102) pour intégrer dans le temps la différence d'épaisseur produite par ledit soustracteur (1), une mémoire (104) pour stocker des données de séquence de temps passé de quantités de fonctionnement d'un dispositif de réglage d'épaisseur (12b) pendant un temps mort L égal à la somme du temps mort L_1 et d'un temps L_2 jusqu'à ce que la jauge d'épaisseur (10) atteigne une extrémité de la couche après détection de l'épaisseur à la position prédéterminée, un calculateur opérationnel (103) pour produire les données de séquence de temps passé de quantités de fonctionnement du dispositif de réglage d'épaisseur (12b) stockées dans ladite mémoire, et une valeur estimée de variable d'état à un temps précédant celui où la valeur de consigne de la valeur détectée de l'épaisseur de la couche a été introduite du temps mort L, un modificateur d'état (105) pour recevoir une sortie dudit intégrateur (102) et une sortie dudit calculateur opérationnel (103) et multiplier chacune desdites sorties dudit intégrateur (102) et calculateur opérationnel (103) par un coefficient pour modifier l'état du temps mort L pour produire une valeur estimée d'état à un temps prédéterminé, un dispositif de prévision d'état (106) pour recevoir les données de séquence de temps passé de quantités de fonctionnement du dispositif de réglage d'épaisseur (12b) stockées dans

ladite mémoire (104) pour produire une variation d'état basée sur l'établissement de l'entrée, depuis un certain temps jusqu'à un temps après l'écoulement du temps mort L, un additionneur (107) pour additionner une sortie dudit modificateur d'état (105) et une sortie dudit dispositif de prévision d'état (106) pour produire la valeur estimée d'état au temps prédéterminé, et un dispositif de commande de quantité de fonctionnement (108) pour multiplier une valeur estimée d'état à un certain temps produite par ledit additionneur par un gain de rétroaction d'état pour produire une valeur de commande de quantité de fonctionnement dudit dispositif de réglage d'épaisseur (12b).

2. Dispositif de commande selon la revendication 1, où lesdites équations d'état sont données par

$$\dot{x}(t) = Ax(t) + Bu(t) \quad (2)$$

$$y(t) = Cx(t - L) \quad (4)$$

où x est un vecteur d'état, u est un vecteur d'entrée dans lequel $u(t) = [u_1(t), u_2(t), u_3(t), u_4(t), u_5(t)]^T$ (où T représente transposition), y est un vecteur de sortie dans lequel $y(t)= [y_1(t), y_2(t), y_3(t), y_4(t), y_5(t)]^T$, et les équations d'état (2) et (3) sont contrôlables et observables.

3. Dispositif de commande selon la revendication 2, où ledit intégrateur (102) réalise le calcul suivant:

$$\bar{X}_I(t) = -\int_0^{t-L} C_i X(\tau)\,d\tau - \int_{t-L}^{t} C_i X(\tau)\,d\tau \qquad (6)$$

où Ci est la i-ième rangée de la matrice C.

4. Dispositif de commande selon la revendication 3, où lorsque $\omega(t)=x(t-L)$, ledit calculateur opérationnel (103) calcule une valeur estimée $\hat{X}(t-L)$ pour $x(t - L)$ sur la base des équations pour $\omega(t)$ suivantes:

$$\omega(t) = A\omega(t) + Bu(t - L) \quad (18)$$

$$y(t) = C\omega(t) \quad (19)$$

5. Dispositif de commande selon la revendication 4, où ladite équation (18) est l'équation discrete suivante:

$$\omega(t_{k+1}) = e^{A(t_{k+1}-t_k)}\omega(t_k) + \int_{t_k}^{t_{k+1}} e^{A(t_{k+1}-\tau)}$$

$$Bu(\tau - L)\,d\tau$$

6. Dispositif de commande selon la revendication 6, où lorsque $\eta = t_{k+1}-\tau$, une valeur estimée $\hat{\omega}(k+1)$ pour $\omega(t_{k+1})$ est calculée par les équations suivantes:
dans le cas de $2 \leqq L < T$,

$$\tilde{\omega}(k+1) = \phi\,\hat{\omega}(k) + \Gamma_1 u(k-3) + \Gamma_2 u(k-2) \qquad (29)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K[y(k+1) - C\tilde{\omega}(k+1)] \qquad (30)$$

où K est une matrice de gain de rétroaction dudit calculateur opérationnel (108), et dans le cas de $T<L<2T$,

$$\tilde{\omega}(k+1) = \phi\,\hat{\omega}(k) + \Gamma_1 u(k-2) + \Gamma_2 u(k-1) \qquad (33)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K[y(k+1) - C\tilde{\omega}(k+1)] \qquad (34)$$

où

$$\phi = e^{AT} \quad (23)$$

$$\Gamma_1 = \int_m^T e^{A\eta} B\,d\eta \qquad (24)$$

$$\Gamma_2 = \int_0^m e^{A\eta} B\,d\eta \qquad (25)$$

$$m = 3T - L \quad (26)$$

7. Dispositif de commande selon revendication 1, où ledit dispositif de commande comporte les constituants suivants :

(1) une valeur détectée y(k+1) d'épaisseur de couche (vecteur constitué de $y_1(k+1)$, $y_2(k+1)$, $y_3(k+1)$, $y_4(k+1)$ et $y_5(k+1)$) est obtenue au travers de la jauge d'épaisseur (10) et un échantillonneur (100) au temps d'exécution de calcul $t=t_{k+1}$ de l'intervalle de temps T; l'échantillonneur (100) se ferme pour chaque temps d'exécution de calcul $t=t_{k+1}$, c'est-à-dire, l'échantillonneur (100) se ferme chaque fois que la jauge d'épaisseur (10) atteint l'extrémité Ⓑ ou Ⓒ de la couche représentée dans la Figure 8 ; de plus, lorsque la jauge d'épaisseur (10) atteint l'extrémité Ⓑ ou Ⓒ de la couche, la jauge (10) produit le signal d'identification d'extrémité d'arrivée d qui indique l'extrémité que la jauge d'épaisseur (10) a atteinte;

(2) une valeur $y_3(k+1)$ de la valeur y(k+1) détectée d'épaisseur de couche est fournie au soustracteur (101) qui produit la déviation d'épaisseur $\varepsilon(k+1)=r_3(k+1)-y_3(k+1)$ entre la valeur détectée $y_3(k+1)$ et une valeur de consigne d'épaisseur $r_3(k+1)$;

(3) l'intégrateur (102) reçoit la déviation d'épaisseur $\varepsilon(k+1)$ du soustracteur (101) et produit une valeur intégrée dans le temps de la déviation d'épaisseur, à partir de l'équation suivante:

$$X_I(k+1) = X_I(k) + 0.5(t_{k+1} - t_k)\{\varepsilon(k) + \varepsilon(k+1)\} \quad (40)$$

où $\varepsilon(k)$ est la déviation d'épaisseur au dernier temps de détection d'épaisseur ($t=t_k$) et $X_1(k)$ est une sortie de l'intégrateur (102) à $t=t_k$;

l'intégrateur (102) inclut une fonction d'un compensateur de perturbation externe, et sert à compenser de la chaleur externe faisant varier l'épaisseur y_3 par de la chaleur générée par l'élément de chauffage, si bien que l'épaisseur y_3 est toujours ajustée pour être une valeur de consigne;

(4) lorsque la jauge d'épaisseur atteint l'une ou l'autre des extrémités de la couche, la jauge d'épaisseur produit le signal d'identification d'extrémité d'arrivée d; $\omega(k+1)$ est calculé à partir des équations (29) et (30) ou (33) et (34) en réponse au signal d'identification d; plus particulièrement, dans les équations (29) et (30) pour les données de la séquence de temps passé de chaleur générée par l'élément de chauffage (108), stockées en mémoire (104), u(k-3) et u(k-2) sont fournies au calculateur opérationnel (103), tandis que dans les équations (33) et (34), u(k-2) et u(k-1) ainsi que la valeur détectée d'épaisseur de couche y(k+1) sont fournies au calculateur opérationnel (103), qui produit une valeur estimée $\hat{X}(t_{k+1}-L)=\hat{\omega}(k+1)$ de la variable d'état au temps $t_{(k+1} - L)$ précédant le temps t_{k+1} du temps mort L déterminée par le signal d'identification d'extrémité d'arrivée d produit par la jauge d'épaisseur;

(5) dans le calcul du premier terme du membre droit de l'équation (39), la valeur estimée d'état $[X_I((k+1), \hat{\omega}(k+1)]^T$ au temps $t_{(k+1}-L)$ est multipliée par un coefficient $e^{\overline{AL}}$ pour modifier l'état au temps mort L, pour obtenir la valeur estimée d'état $e^{\overline{AL}}[X_I(k+1),\hat{\omega}(k+1)]^T$ au temps t_{k+1}; c'est-à-dire la sortie $X_I(k+1)$ de l'intégrateur (102) et la sortie $\hat{\omega}(k+1)$ du calculateur opérationnel (103) sont fournies au modificateur d'état (105) qui les multiplie par le coefficient, pour changer l'état au temps mort L, déterminé par le signal d'identification d'extrémité d'arrivée d de la jauge d'épaisseur, pour obtenir la valeur estimée d'état au temps t_{k+1}; étant donné que la grandeur mort L diffère selon l'extrémité de la couche que la jauge d'épaisseur atteint, le coefficient $e^{\overline{AL}}$ diffère selon la position de la jauge d'épaisseur à l'exécution du calcul, c'est-à-dire, le signal d'identification d'extrémité d'arrivée d de la jauge d'épaisseur;

le changement d'état par l'entrée u(k) appliqué en domaine temps uniquement pendant le temps mort L est exprimé par le second terme I(k+1) du membre droit de l'équation (39) et la correction correspondante est réalisée par le dispositif de prévision d'état (106);

(6) le second terme I(k+1) du membre droit de l'équation (39) exprime une quantité de modification d'état pour les données d'entrée de séquence de temps u(k-2), u(k-1), et u(k) appliquées au domaine de temps, du temps $(t_{k+1} - L)$ au temps t_{k+1}: I(k+1) est calculé à partir de l'équation (37) ou (38), en fonction de l'extrémité de la couche que la jauge dépaisseur atteint, c'est-à-dire, en fonction du signal d'identification d'extrémité d'arrivée produit par la jauge d'épaisseur, plus particulièrement, les données passées, séquentielles selon le temps, de la chaleur générée par l'élément de chauffage (dans ce cas, trois données de u(k-2), u(k-1), et u(k)), déterminées par la grandeur du temps mort L stocké dans la mémoire (104), sont fournies au dispositif de prévision d'état (106), et la quantité de variation d'état I(k+1) par l'entrée u(k) du temps $(t_{k+1} - L)$ au temps t_{k+1} est produite;

(7) la sortie $e^{\overline{AL}}[X_I(k+1),\hat{\omega}(k+1)^T$ du modificateur d'état (105) et la sortie I(k+1) du dispositif de prévision d'état (106) sont additionnées dans l'additionneur (107) qui produit la valeur estimée d'état $[\hat{\hat{X}}_I(k+1),\hat{X}(k+1)]^T$ au temps t_{k+1}; de cette manière, bien que le calculateur opérationnel (103) puisse n'obtenir que la valeur estimée d'état au temps t_{k+1}-L à cause du temps mort L, la valeur estimée d'état

au temps t_{k+1}peut être obtenue par intégration dans le modificateur d'état (105) et le dispositif de prévision d'état (106) pour le temps mort L; l'influence du retard de phase dû au temps mort L peut être éliminée par cette opération;

(8) une quantité u(k-1) de chaleur générée par l'élément de chauffage (12a) du temps t_{k+1}au prochain temps de calcul t_{k+2} est définie par l'équation suivante qui utilise le gain de rétroaction d'état (f_1, F_2);

$$u(k+1) = -f_1\hat{\hat{X}}_I(k+1) - F_2\hat{X}(k+1) \quad (41)$$

l'additionneur (107) fournit la valeur estimée d'état $[\hat{\hat{X}}(k+1), \hat{X}(k+1)]^T$ au temps t_{k+1}à un dispositif de commande (108) pour de la chaleur générée par l'élément de chauffage; le dispositif de commande (108) multiplie la valeur estimée d'état $[\hat{\hat{X}}(k+1), \hat{X}(k+1)]^T$ par le gain de rétroaction d'état, pour déterminer une valeur de commande de chaleur générée par l'élément de chauffage; et

(9) le calcul de commande ci-dessus est exécuté après que la valeur détectée suivante y(k+2) d'épaisseur de couche soit obtenue de l'échantillonneur (100) au temps $t=t_{k+2}$de l'exécution du calcul, lorsque la jauge d'épaisseur est déplacée dans la largeur de la couche après la période de temps T, et qu'elle atteint l'extrémité opposée de la couche, lesdites équations (37), (38), (39) étant les suivantes :

$$I(k+1) = e^{\hat{A}(2T)}\int_0^{L-2T} e^{\hat{A}\sigma}\bar{B}d\sigma\, u(k-2) + e^{\hat{A}T}\int_{\delta}^{T} e^{\hat{A}\sigma}\bar{B}d\sigma\, u(k-1) + \int_0^T e^{\hat{A}\sigma}\bar{B}d\sigma\, u(k) \quad (37)$$

$$I(k+1) = e^{\hat{A}T}\int_0^{L-T} e^{\hat{A}\sigma}Bd\sigma\, u(k-1) + \int_{\delta}^{T} e^{\hat{A}\sigma}\bar{B}d\sigma\, u(k) \quad (38)$$

$$\begin{pmatrix}\hat{\hat{X}}_I(k+1)\\ \\ \hat{X}(k+1)\end{pmatrix} = e^{\hat{A}L}\begin{pmatrix}X_I(k+1)\\ \\ \hat{\omega}(k+1)\end{pmatrix} + I(k+1) \quad (39)$$

8. Dispositif de commande selon la revendication 7, dans lequel la matrice de rétroaction F dudit dispositif de commande de valeur de fonctionnement (108), est choisie de façon à ce que chacune des valeurs propres de la matrices ($\bar{A}$-$\bar{B}\bar{F}$) soient dans une région stable.

9. Un dispositif de commande selon la revendication 4, dans lequel ledit calculateur opérationnel (108) calcule la valeur estimée $\hat{\omega}$(k+1) pour $\omega(t_{k+1})$ à partir des équations suivantes:
l'équation de calcul de la valeur estimée $\hat{\omega}$(k+1) pour l'extrémité Ⓑ est donnée par

$$\tilde{\omega}(k+1) = \phi_B\hat{\omega}(k) + \int_0^{m_B} e^{\hat{A}\eta}Bd\eta\, u(k-1) + \int_{m_B}^{T-L_B+L_C} e^{\hat{A}\eta}\bar{B}d\eta\, u(k-2) \quad (55)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K_B[y(k+1) - C\tilde{\omega}(k+1)] \quad (56)$$

où

$$\phi_B = e^{A(T - L_B + L_C)}$$

K_B = matrice de gain du calculateur opérationnel (103),

l'équation de calcul de la valeur estimée $\hat{\omega}(k+1)$ pour l'extrémité Ⓒ est donnée par

$$\tilde{\omega}(k+1) = \phi_C \hat{\omega}(k) + \int_0^{m_C} e^{A\eta} B d\eta \; u(k-1) + \int_{m_C}^{T-L_C+L_B} e^{A\eta} B d\eta \; u(k-2) \qquad (57)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K_C[y(k+1) - C\tilde{\omega}(k+1)] \qquad (58)$$

où

$$\phi_C = e^{A(T - L_C + L_B)}$$

K_C= matrice de gain du calculateur opérationnel.

10. Dispositif de commande selon la revendication 1, où ledit dispositif de commande comprend les constituants suivants:

(1) la valeur détectée d'épaisseur de couche $y(k+1)$ (vecteur constitué de $y_1(k+1$, $y_2(k+1)$, $y_3(k+1)$, $y_4(k+1)$et $y_5(k+1)$), est obtenu au travers de la jauge d'épaisseur (10) et l'échantillonneur (100), au temps d'exécution du calcul $t=t_{k+1}$ de l'intervalle de temps T; l'échantillonneur (100) se ferme pour chaque temps d'exécution du calcul $t=t_{k+1}$, c'est-à-dire, l'échantillonneur (100) se ferme chaque fois que la jauge d'épaisseur (10) atteint l'extrémité Ⓑou Ⓒde la couche représentée dans la Figure 8 ; lorsque la jauge d'épaisseur (10) atteint l'extrémité Ⓑou Ⓒde la couche, la jauge (10) produit le signal d'identification d'extrémité d'arrivée d qui indique l'extrémité atteinte par la jauge;

(2) une valeur $y_3(k+1)$ de la valeur détectée d'épaisseur de couche $y(k+1)$ est fournie au soustracteur (101) qui produit la déviation d'épaisseur $\varepsilon(k+1) = r_3(k+1)-y_3(k+1)$ entre la valeur détectée $y_3(k+1)$ et une valeur d'épaisseur de consigne $r_3(k+1)$;

(3) l'intégrateur (102) reçoit la déviation d'épaisseur $\varepsilon(k+1)$ du soustracteur (101) et produit une valeur intégrée dans le temps de la déviation d'épaisseur à partir de l'équation suivante:

$$X_I(k + 1) = X_I(k) + 0.5(t_{k-1} - t_k)\{\varepsilon(k) + \varepsilon(k + 1)\} \qquad (69)$$

où $\varepsilon(k)$ est la déviation d'épaisseur au dernier temps de détection d'épaisseur ($t=t_k$) et $X_I(k)$ est une sortie de l'intégrateur (102) à $t=t_k$;

l'intégrateur (102) inclut une fonction d'un compensateur de perturbation externe et sert à compenser de la chaleur externe faisant varier l'épaisseur y_3 par de la chaleur générée par l'élément de chauffage de façon à ce que l'épaisseur y_3 soit toujours ajustée pour être une valeur de consigne;

(4) lorsque la jauge d'épaisseur atteint l'une ou l'autre des extrémités de la couche, la jauge d'épaisseur produit le signal d'identification d'extrémité d'arrivée d; $\hat{\omega}(k+1)$ est calculé à partir des équations (55) et (56) ou (57) et (58) en réponse au signal d'identification d; les données de séquence de temps passé u(k-2) et u(k-1) de chaleur générée par l'élément de chauffage, stockées en mémoire (104) avec la valeur détectée d'épaisseur de couche y(k+1), sont fournies au calculateur opérationnel, qui produit une valeur estimée $\hat{X}(t_{k+1}-L)=\hat{\omega}(k+1)$ de la variable d'état au temps $t(_{k+1}-L)$ précédant le temps t_{k+1} du temps mort L déterminé par le signal d'identification d'extrémité d'arrivée d produit par la jauge d'épaisseur;

(5) dans le calcul du premier terme du membre droit de l'équation (66), la valeur estimée d'état $[X_I(k+1),\hat{\omega}(k+1)]^T$ au temps $t(_{k+1}-L)$ est multipliée par un coefficient $e^{\overline{AL}}$ pour modifier l'état par le temps mort moyen $\bar{L}$ défini par l'équation (68) pour obtenir la valeur estimée d'état $e^{\overline{AL}}[X_I(k+1),\hat{\omega}(k+1)]^T$ au temps t_{k+1}; la sortie $X_I(k+1)$ de l'intégrateur (102) et la sortie $\hat{\omega}(k+1)$ du calculateur opérationnel (103) sont fournies au modificateur d'état (105) qui les multiplie par le coefficient pour modifier l'état par le temps mort moyen L pour obtenir la valeur estimée d'état au temps t_{k+1}, la grandeur au temps mort $\bar{L}$ adopte la valeur moyenne des temps morts pour les deux extrémités de la couche, comme décrit par l'équation (68);

la modification d'état par l'entrée u(k) appliquée en domaine de temps uniquement pendant le temps mort moyen $\bar{L}$, est exprimée par le second terme $\bar{I}(k+1)$ du membre droit de l'équation (66) et la correction correspondante est faite par le dispositif de prévision d'état (106);

(6) le second terme $\bar{I}(k+1)$ du membre droit de l'équation (66) exprime une quantité de modification

d'états pour les données d'entrée de séquence de temps u(k-1) et u(k) appliquées au domaine de temps du temps mort moyen $\bar{L}$, du temps ($t_{k+1}-\bar{L}$) au temps t_{k+1} : $\bar{I}(k+1)$ est calculé à partir de l'équation (67) en utilisant le temps mort moyen $\bar{L}$; les données de séquence de temps passé de la chaleur générée par l'élément de chauffage (dans ce cas, deux données de u(k-1) et u(k)) déterminées par la grandeur du temps mort $\bar{L}$ stocké dans la mémoire (104), sont fournies au dispositif de prévision d'état (106) et la quantité de variation d'état I(k+1) par l'entrée u(k) du temps ($t_{k+1}-\bar{L}$) au temps t_{k+1};
(7) la sortie $e^{\bar{A}\bar{L}}[X_I(k+1),\hat{\omega}(k+1)]^T$ du modificateur d'état (105) et la sortie I(k+1) du dispositif de prévision d'état, sont additionnées dans l'additionneur (107) qui produit la valeur estimée d'état $[\hat{\bar{X}}_I(k+1), \bar{X}(k+1)]^T$ au temps T_{k+1} ; bien que le calculateur opérationnel (103) ne puisse obtenir que la valeur estimée d'état au temps T_{k+1}-L en raison du temps mort L; la valeur estimée d'état au temps T_{k+1} peut être obtenue par intégration dans le modificateur d'état (105) et le dispositif de prévision d'état (106) pour le temps mort $\bar{L}$; l'influence du retard de phase dθ au temps mort L peut être éliminée par cette opération;
(8) une quantité u(k+1) de chaleur générée par l'élément de chauffage du temps t_{k+1} au temps de calcul suivant t_{k+2} est définie par l'équation suivante, qui utilise le gain de rétroaction d'état (f_1, F_2):

$$u(k+1) = -f_1\hat{\bar{X}}_I(k+1) - F_2\hat{X}(k+1) \quad (41)$$

l'additionneur (107) fournit la valeur estimée d'état $[\hat{\bar{X}}(k+1),\hat{X}(k+1)]^T$ au temps t_{k+1} à un dispositif de commande (108) pour de la chaleur générée par l'élément de chauffage; le dispositif de commande (108) multiplie la valeur estimée d'état $[\hat{\bar{X}}(k+1),\hat{X}(k+1)]^T$ par le gain de rétroaction d'état pour déterminer une valeur de commande de chaleur générée par l'élément de chauffage; et
(9) le calcul ci-dessus est exécuté après que la valeur détectée suivante y(k+2) d'épaisseur de couche est obtenue de l'échantillonneur (100) au temps $t=t_{k+2}$ d'exécution de calcul, lorsque la jauge d'épaisseur est déplacée dans la largeur de la couche après la période de temps T et atteint l'extrémité opposée de la couche, lesdits équations (55), (56), (57), (58), (66), (67), (68) étant les suivantes :

$$\tilde{\omega}(k+1) = \phi_B\hat{\omega}(k) + \int_0^{m_B} e^{A\eta}Bd\eta\, u(k-1) + \int_{m_B}^{T-L_B+L_C} e^{A\eta}Bd\eta\, u(k-2) \quad (55)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K_B[y(k+1) - C\tilde{\omega}(k+1)] \quad (56)$$

où

$$\phi_B = e^{A(T-L_B+L_C)}$$

$$\tilde{\omega}(k+1) = \phi_C\hat{\omega}(k) + \int_0^{m_C} e^{A\eta}Bd\eta\, u(k-1) + \int_{m_C}^{T-L_C+L_B} e^{A\eta}Bd\eta\, u(k-2) \quad (57)$$

$$\hat{\omega}(k+1) = \tilde{\omega}(k+1) + K_C[y(k+1) - C\tilde{\omega}(k+1)] \quad (58)$$

où

$$\phi_C = e^{A(T-L_C+L_B)}$$

$$\begin{bmatrix} \hat{\bar{X}}_I(k+1) \\ \hat{X}(k+1) \end{bmatrix} = e^{\bar{A}\bar{L}} \begin{bmatrix} X_I(k+1) \\ \hat{\omega}(k+1) \end{bmatrix} + \bar{I}(k+1) \quad (66)$$

$$\bar{I}(k+1) = e^{\bar{\Lambda}\bar{T}} \int_{0}^{\bar{L}-T} e^{\bar{\Lambda}\sigma} \bar{B} d\sigma \; u(k-1) + \int_{0}^{T} e^{\bar{\Lambda}\sigma} \bar{B} d\sigma \; u(k) \qquad (67)$$

$$\bar{L} = (L_B + L_C)/2 \qquad (68)$$

FIG. 1

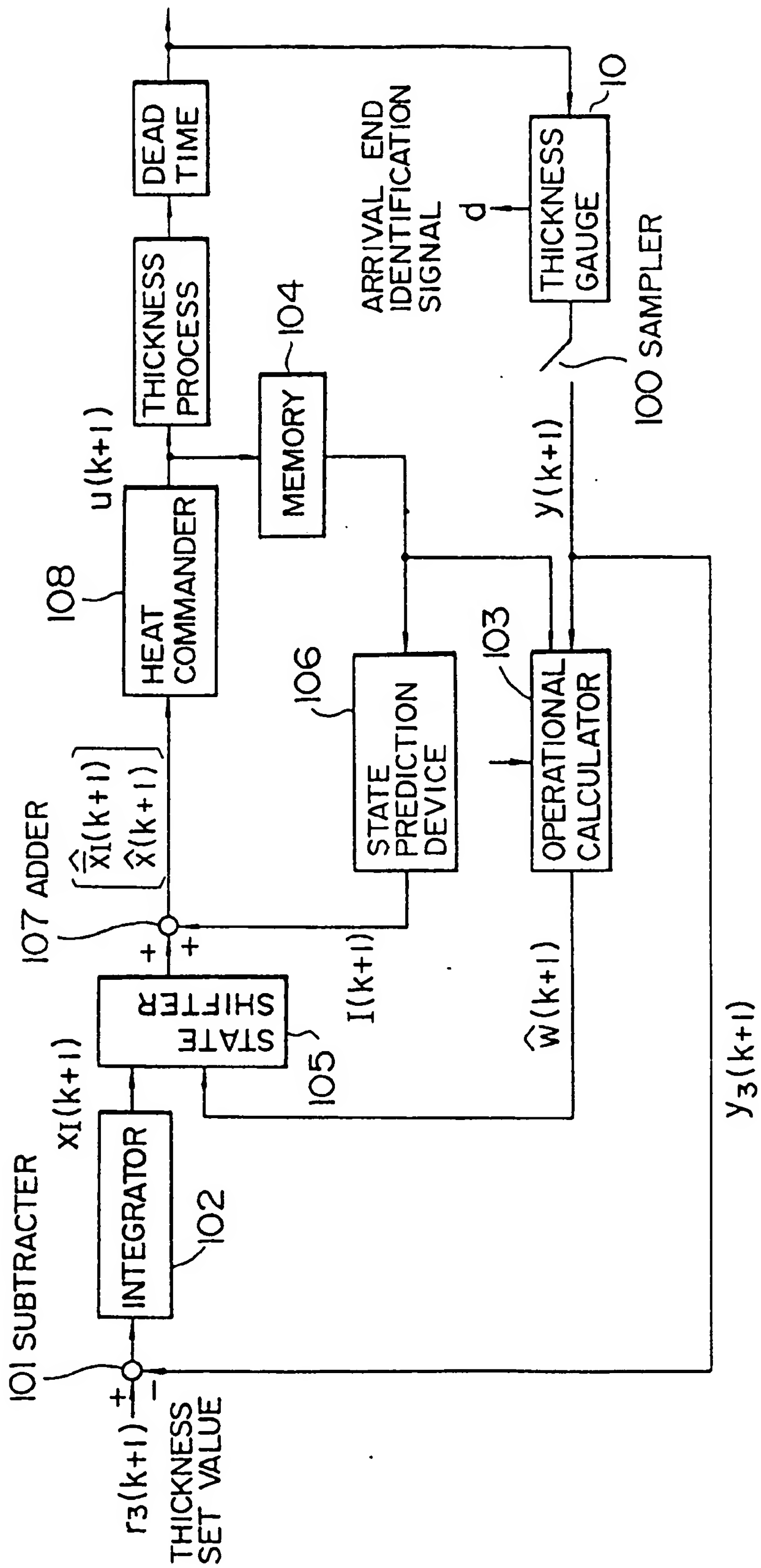

DEAD TIME
THICKNESS PROCESS
HEAT COMMANDER
108
u(k+1)
MEMORY
104
ARRIVAL END IDENTIFICATION SIGNAL
d
THICKNESS GAUGE
10
100 SAMPLER
y(k+1)
STATE PREDICTION DEVICE
106
OPERATIONAL CALCULATOR
103
107 ADDER
$\hat{x}_I(k+1)$
$\hat{x}(k+1)$
+
+
STATE SHIFTER
105
I(k+1)
$\hat{w}(k+1)$
$x_I(k+1)$
INTEGRATOR
102
101 SUBTRACTER
$y_3(k+1)$
$r_3(k+1)$
+
−
THICKNESS SET VALUE

FIG. 2
PRIOR ART

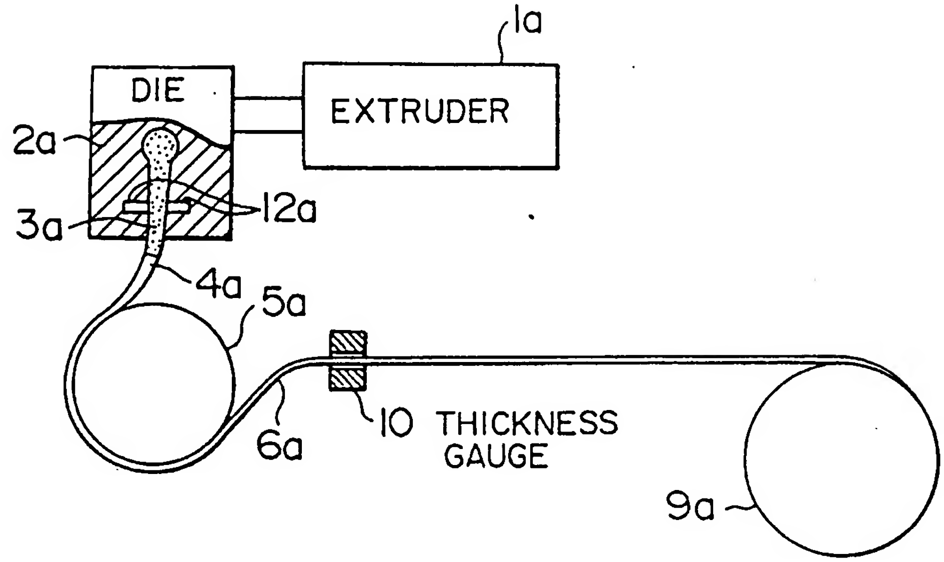


FIG. 3
PRIOR ART

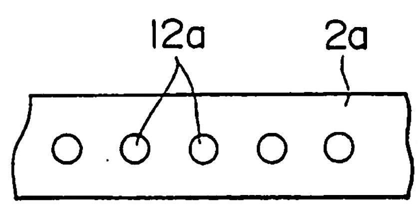


FIG.4
PRIOR ART

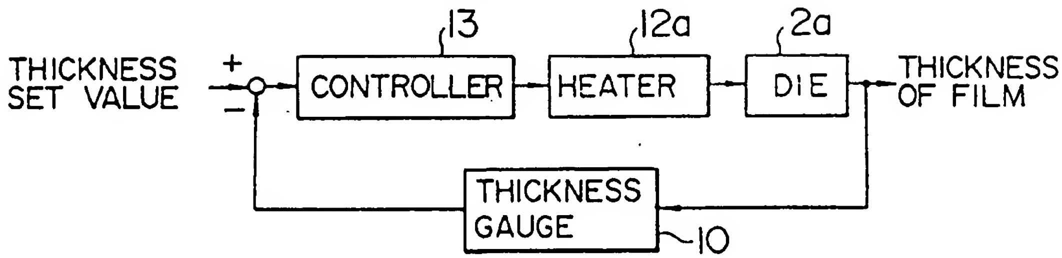


FIG.5(a)

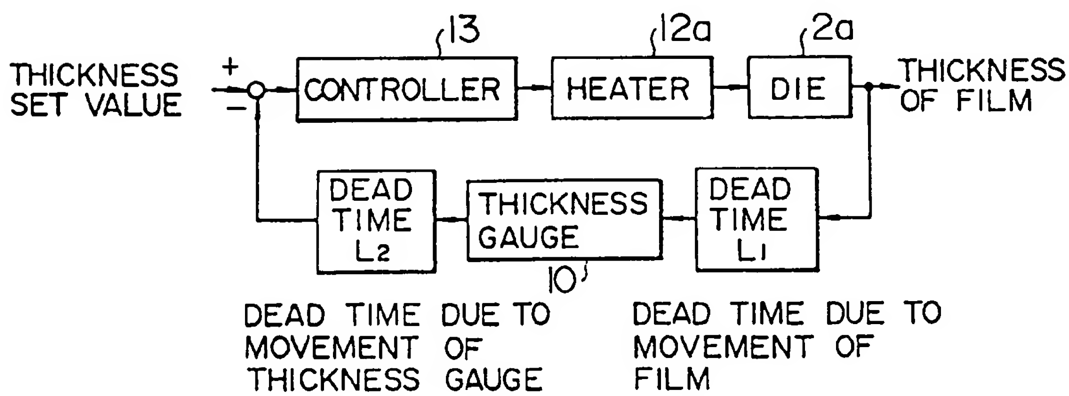


FIG.5(b)

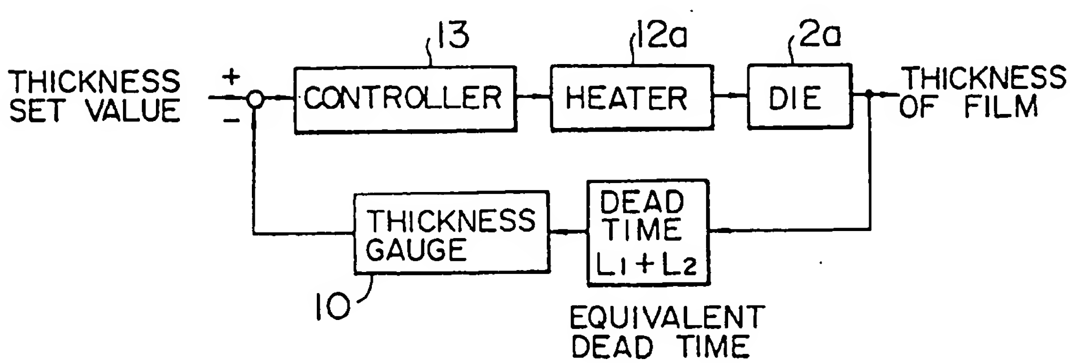


FIG. 6

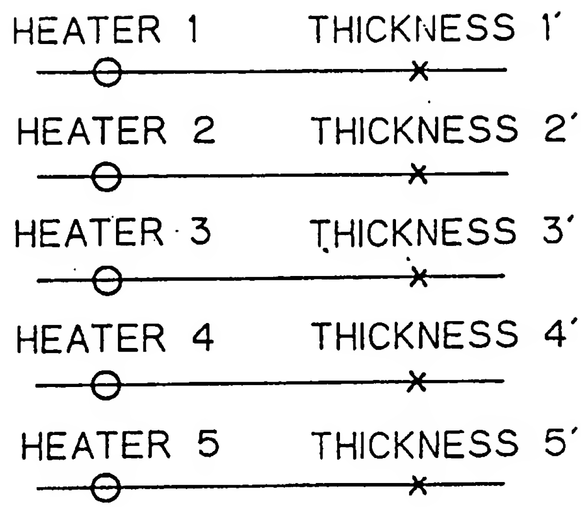

HEATER 1
THICKNESS 1'
HEATER 2
THICKNESS 2'
HEATER 3
THICKNESS 3'
HEATER 4
THICKNESS 4'
HEATER 5
THICKNESS 5'

FIG. 7

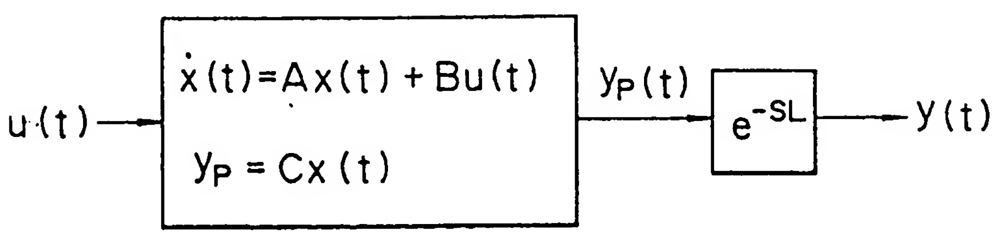

u(t)
$\dot{x}(t) = Ax(t) + Bu(t)$
$y_P = Cx(t)$
$y_P(t)$
e^{-SL}
y(t)

FIG. 8

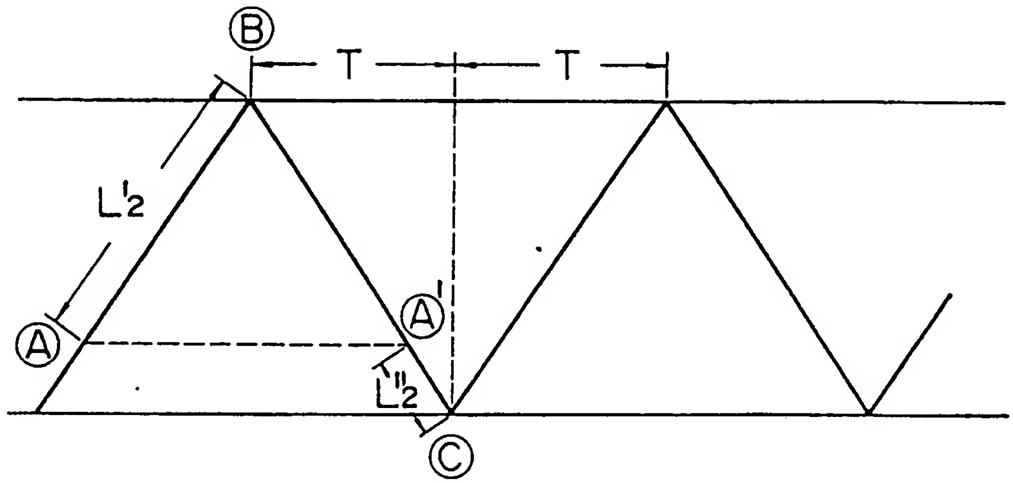


FIG. 9

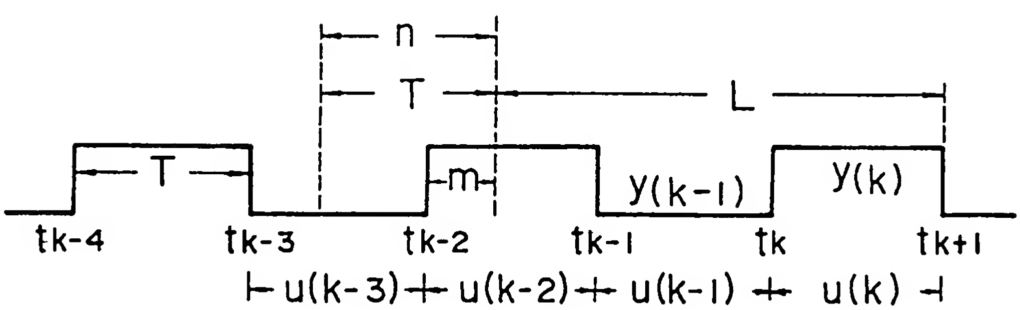


FIG. 10

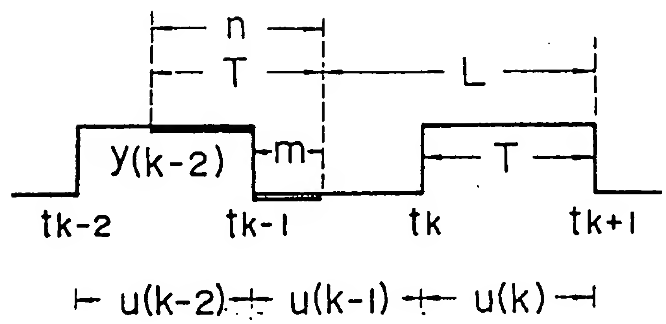


FIG. 11

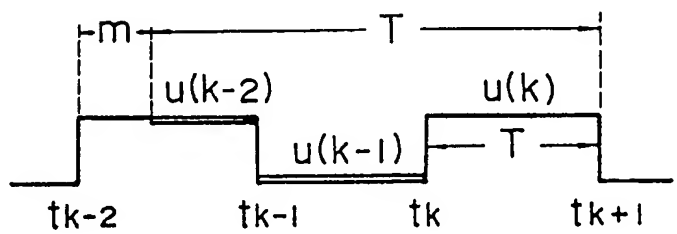
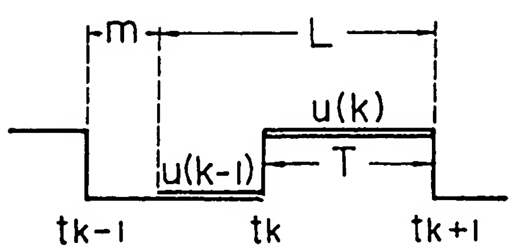
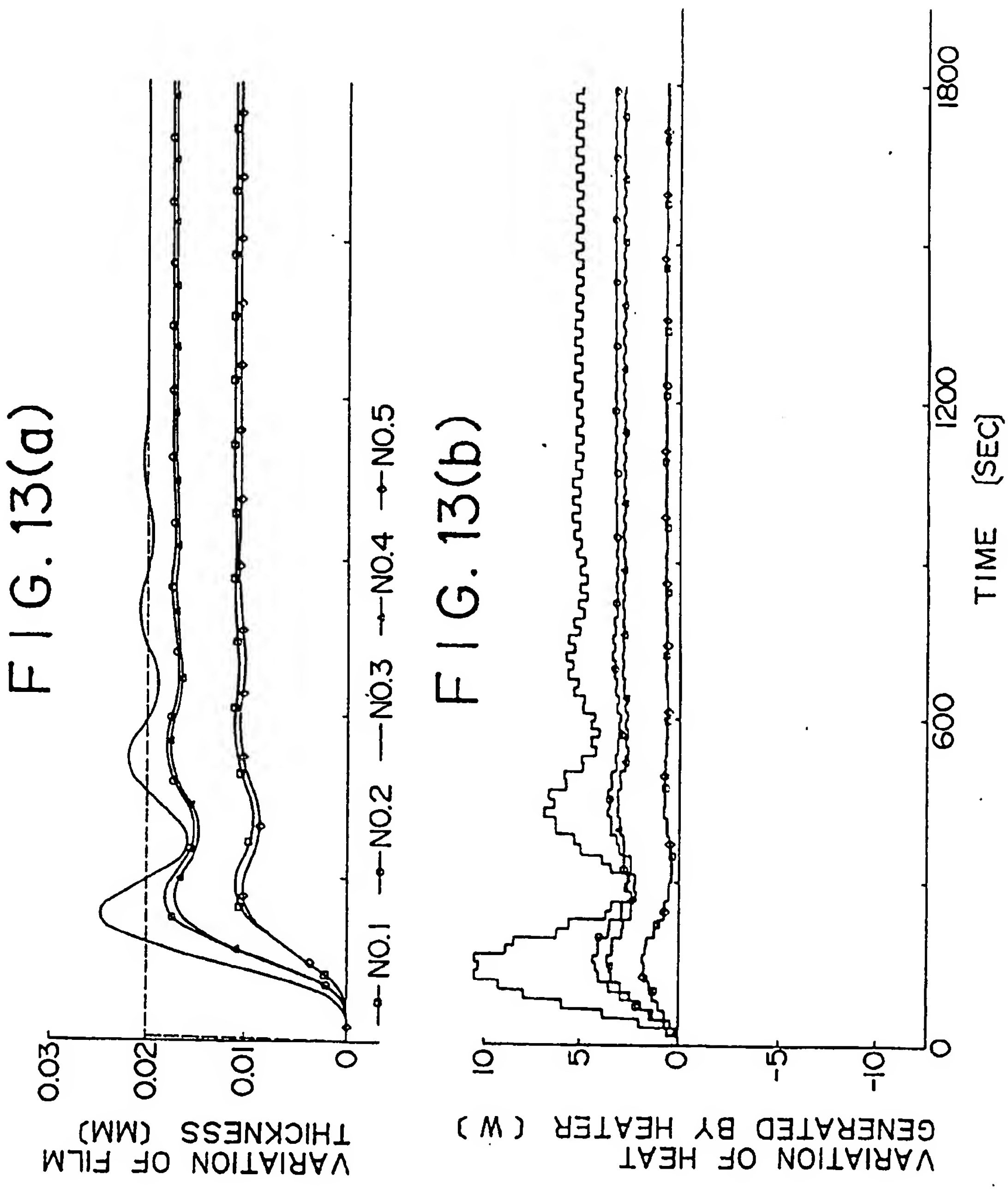


FIG. 12





F I G. 13(a)

F I G. 13(b)

FIG. 14(a)

FIG. 14(b)

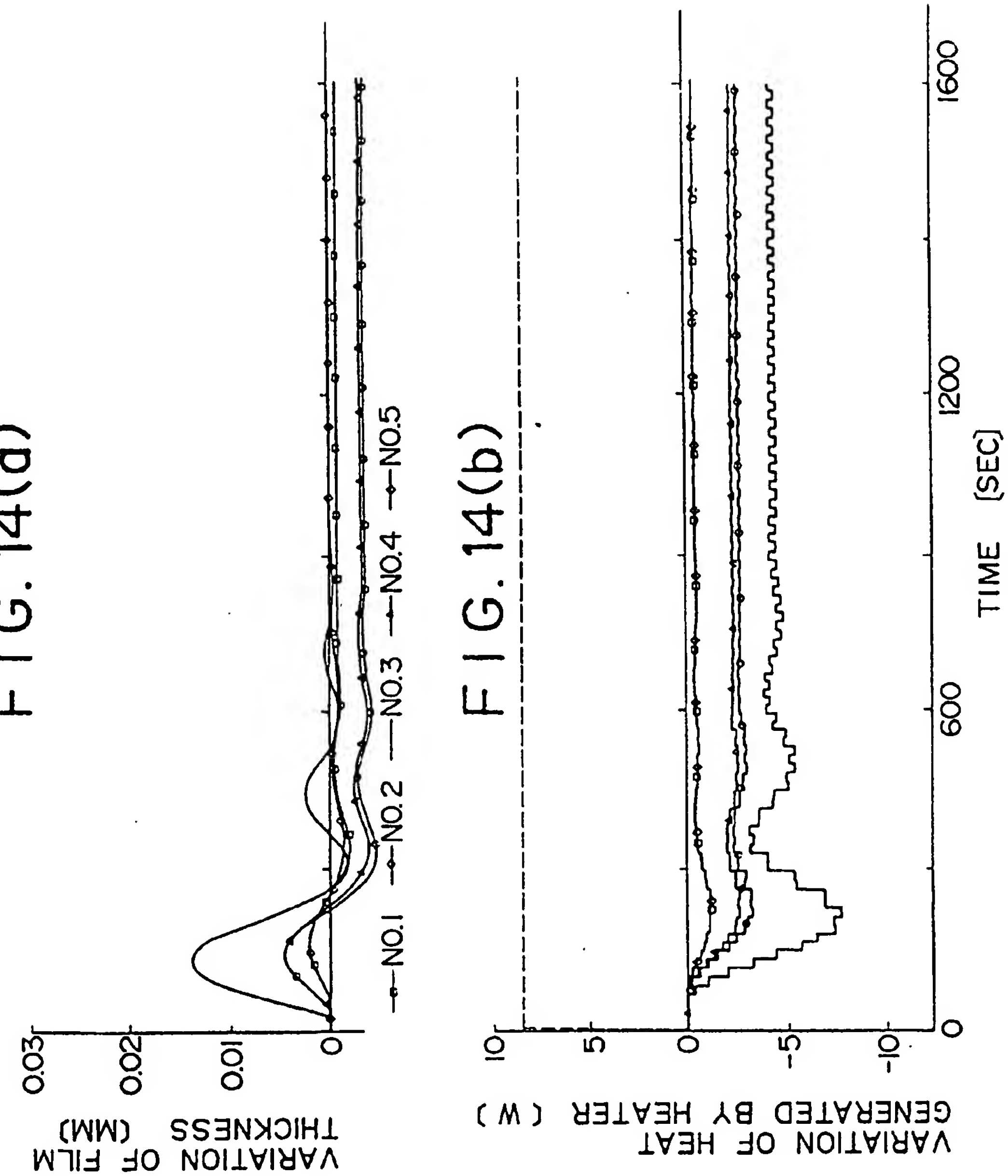


FIG. 15

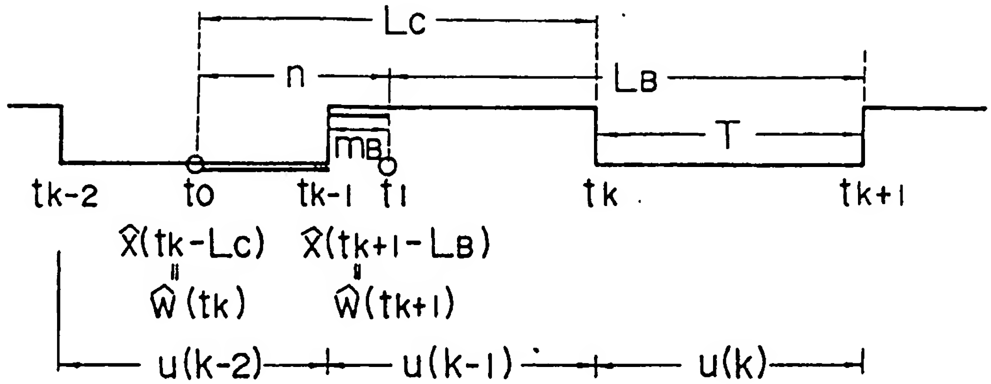


FIG. 16

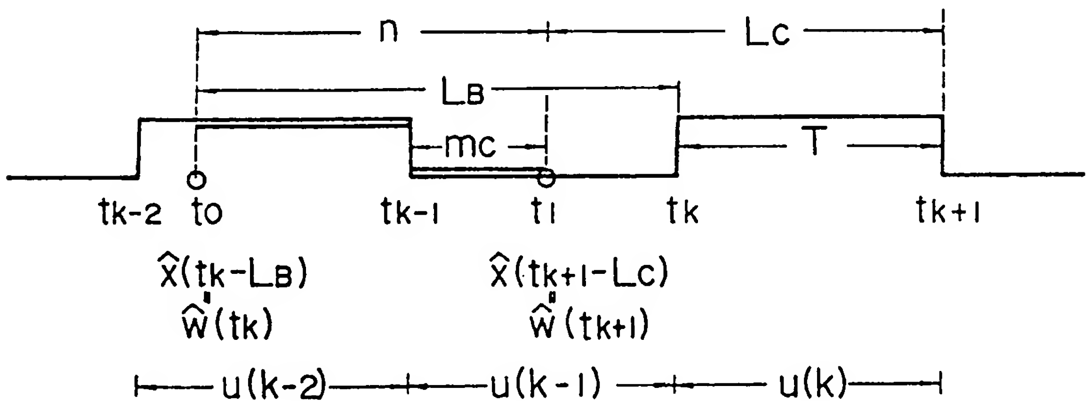


FIG. 17

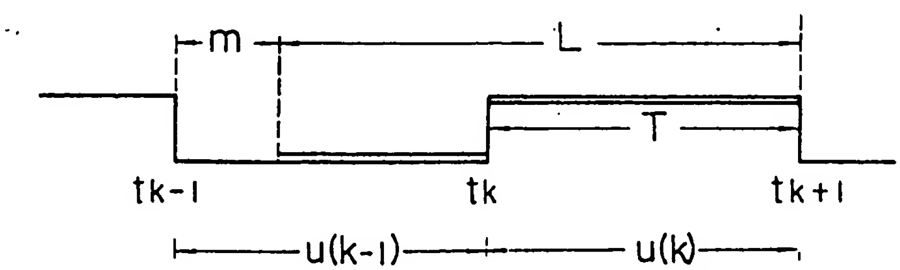


FIG.18(a)

FIG.18(b)

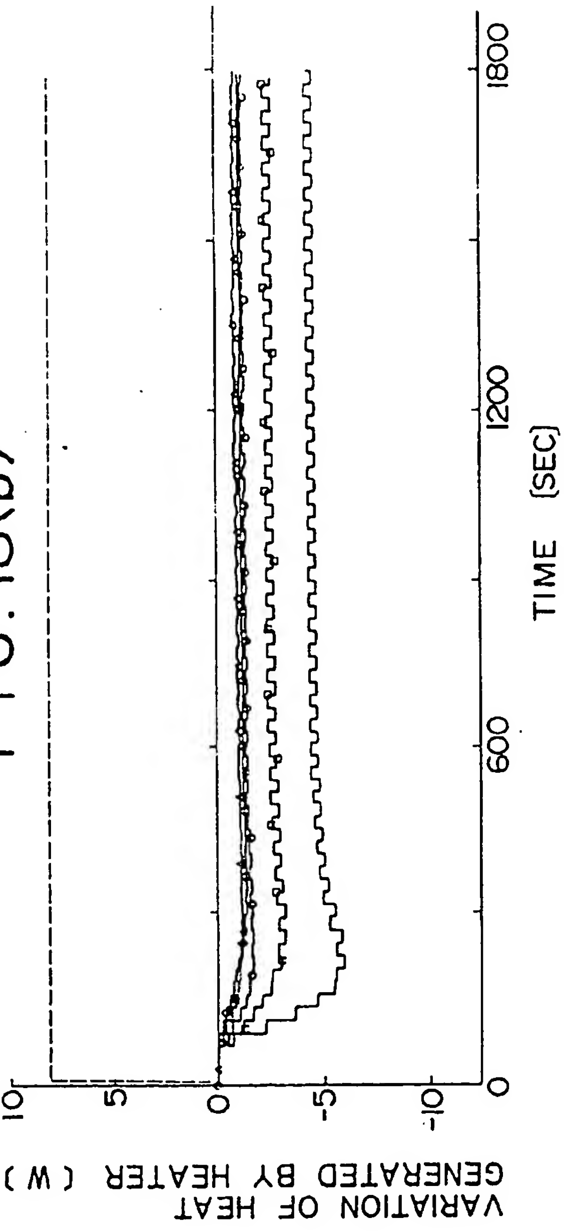
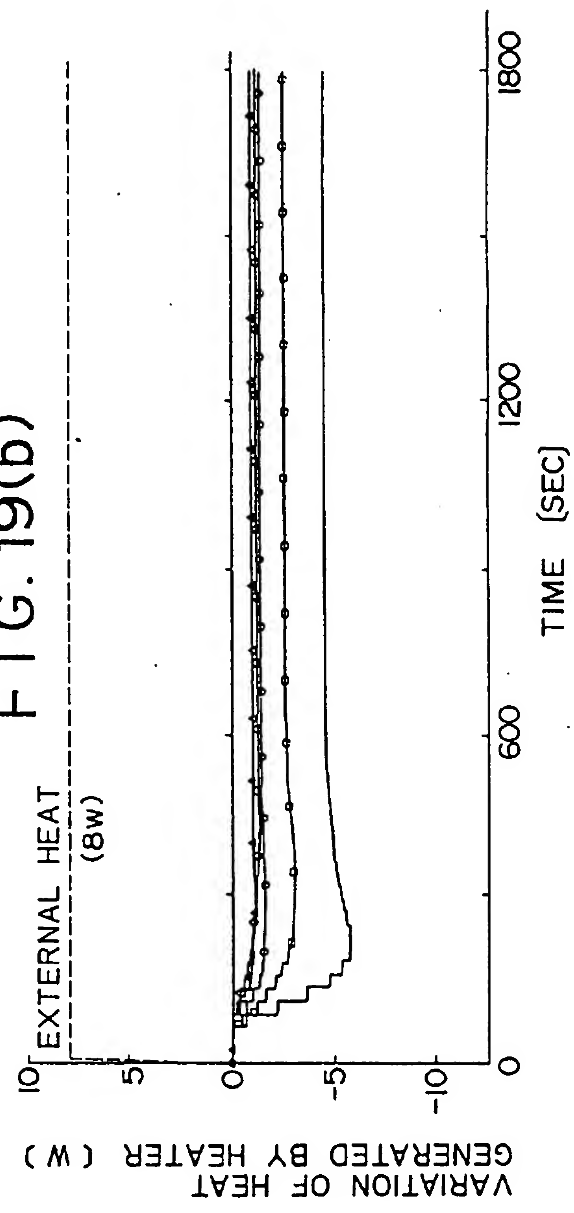


FIG. 19(a)

FIG. 19(b)



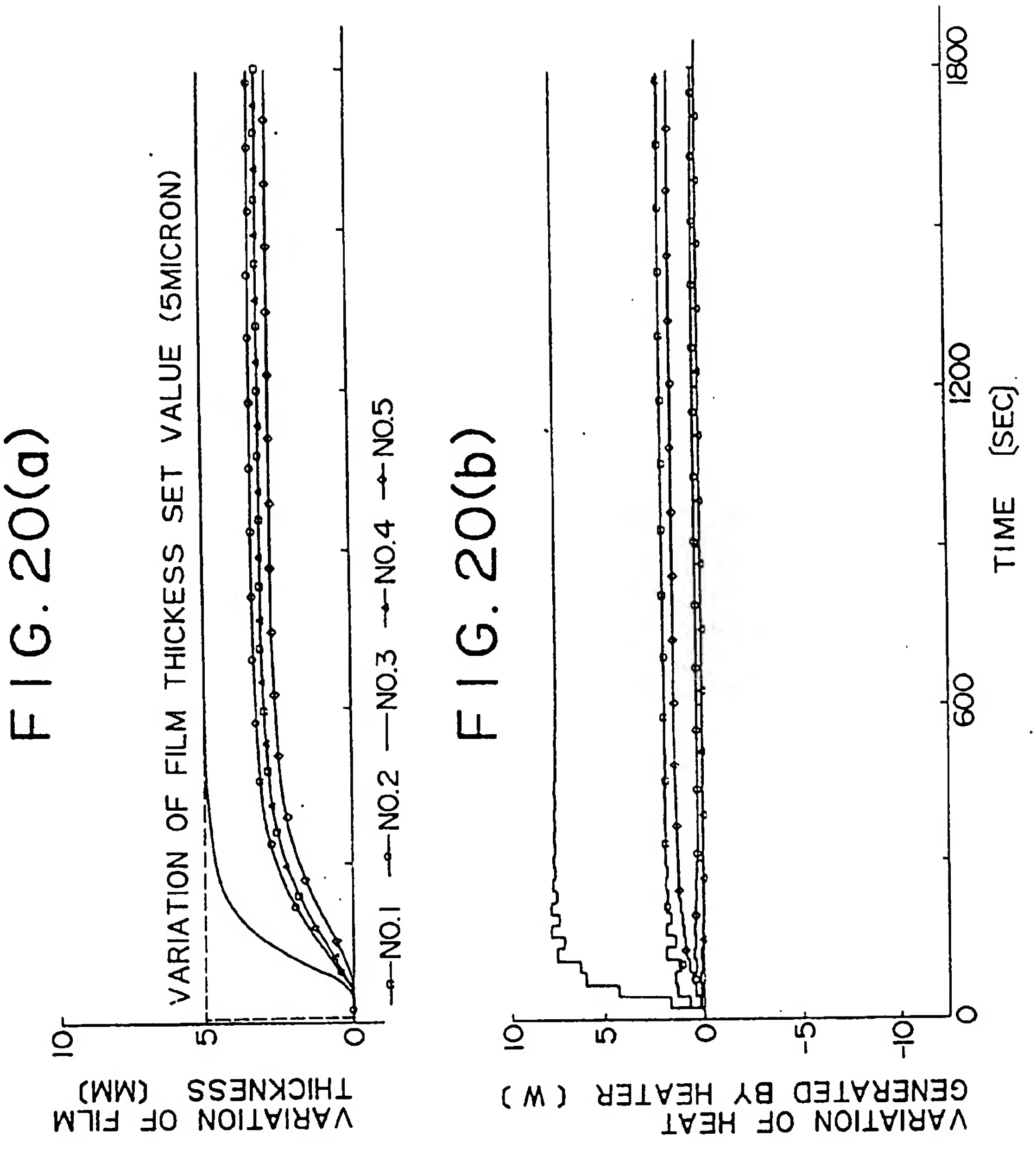


FIG. 20(a)

FIG. 20(b)

FIG. 21(a)

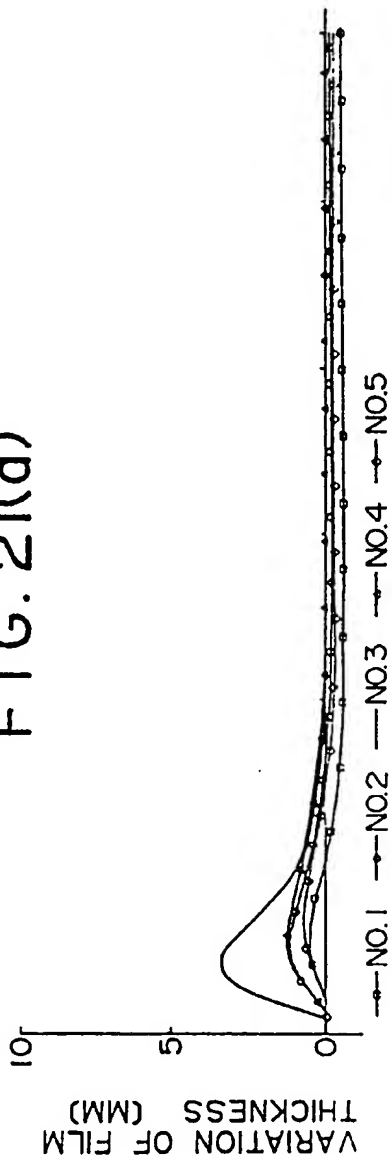


FIG. 21(b)